

Aug. 8, 1944.

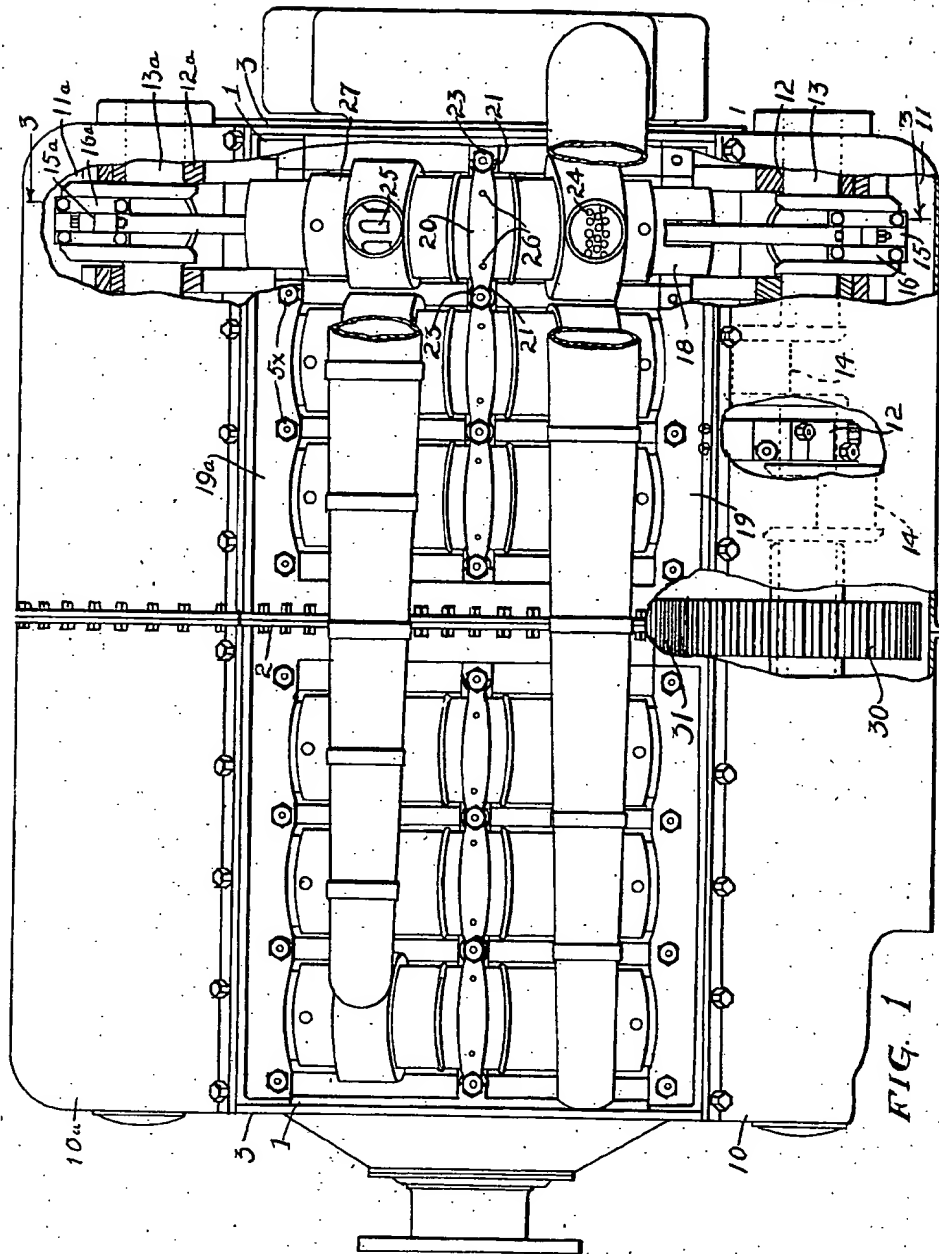
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2,355,379

MULTIPLE PISTON ENGINE

Filed Feb. 1, 1943

5 Sheets-Sheet 1



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MULTIPLE PISTON ENGINE

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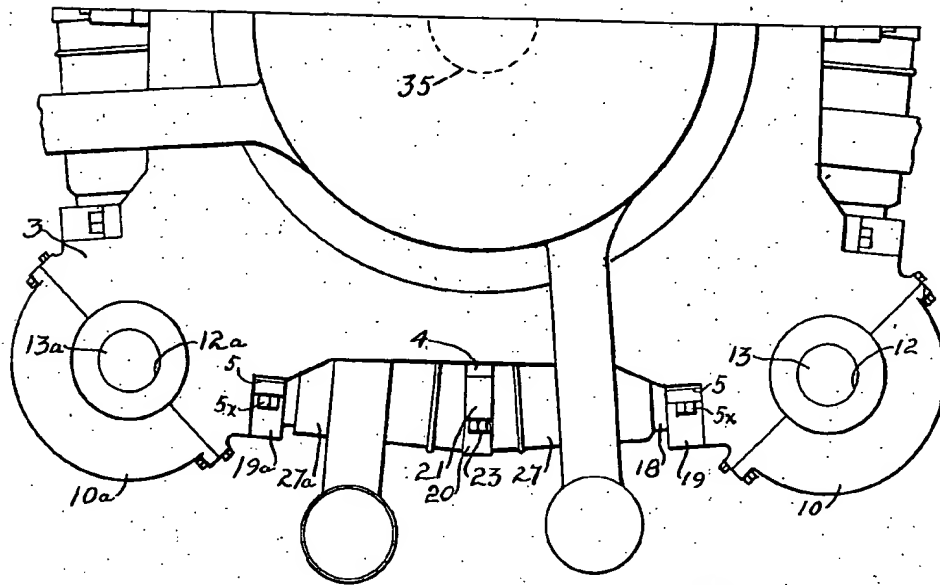


FIG. 2

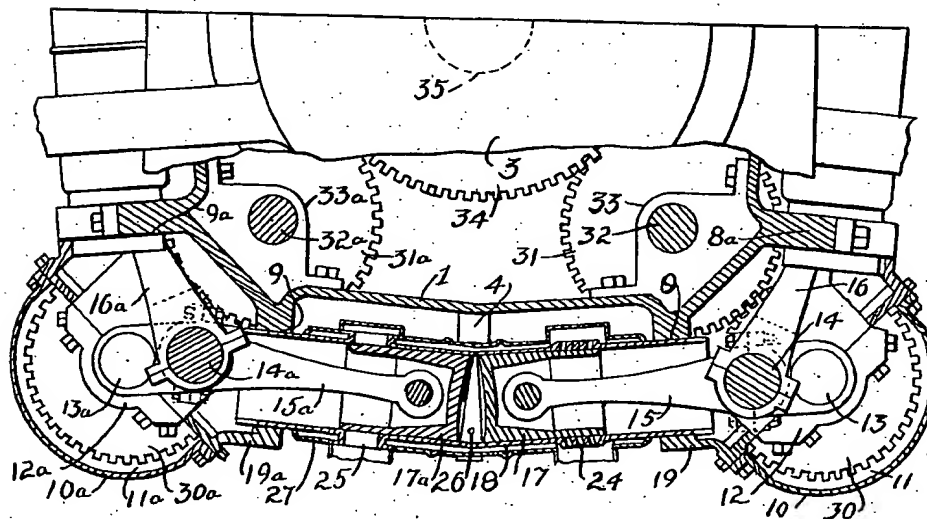


FIG. 3

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5 Sheets-Sheet 3

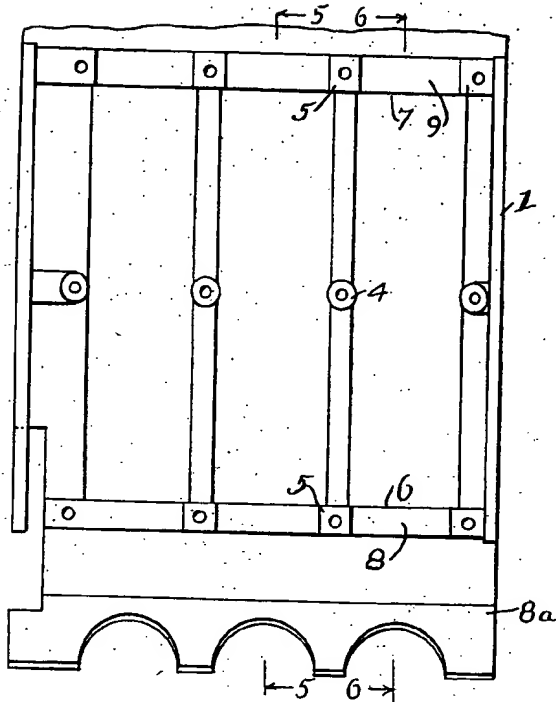


FIG. 4

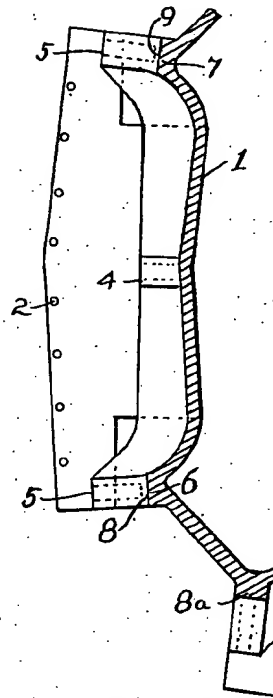


FIG. 5

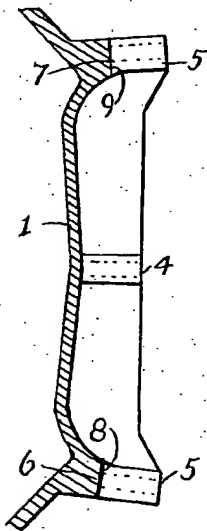


FIG. 6

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5 Sheets-Sheet 4

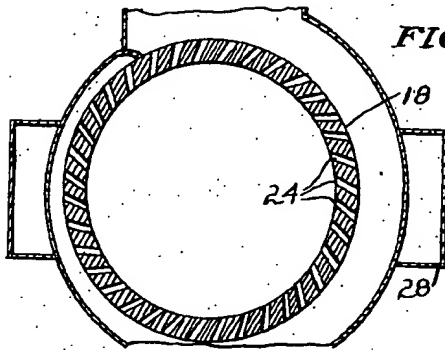


FIG. 7

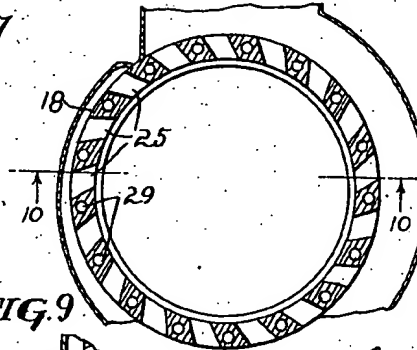


FIG. 9

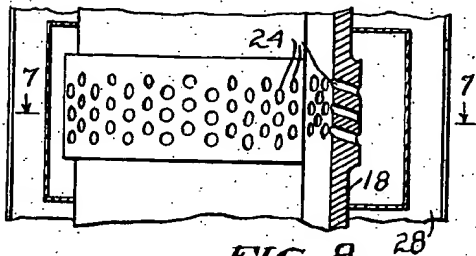


FIG. 8

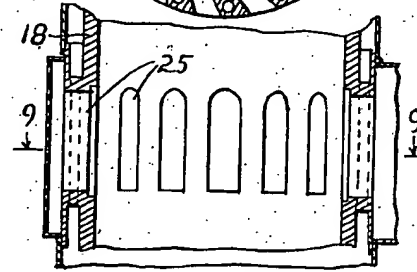


FIG. 10

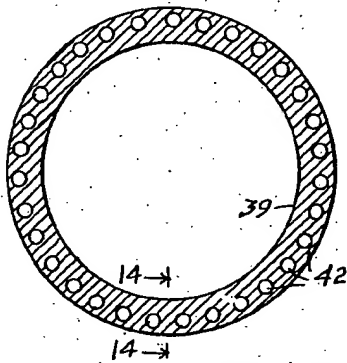


FIG. 13

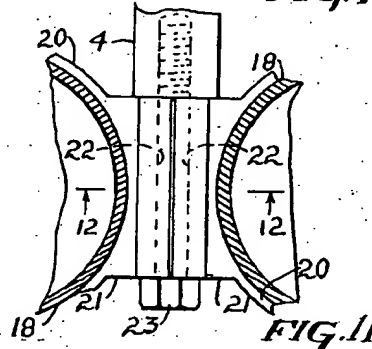


FIG. 11

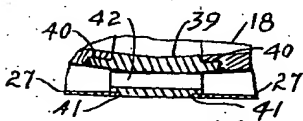


FIG. 14

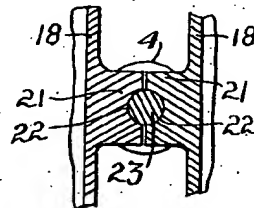


FIG. 12

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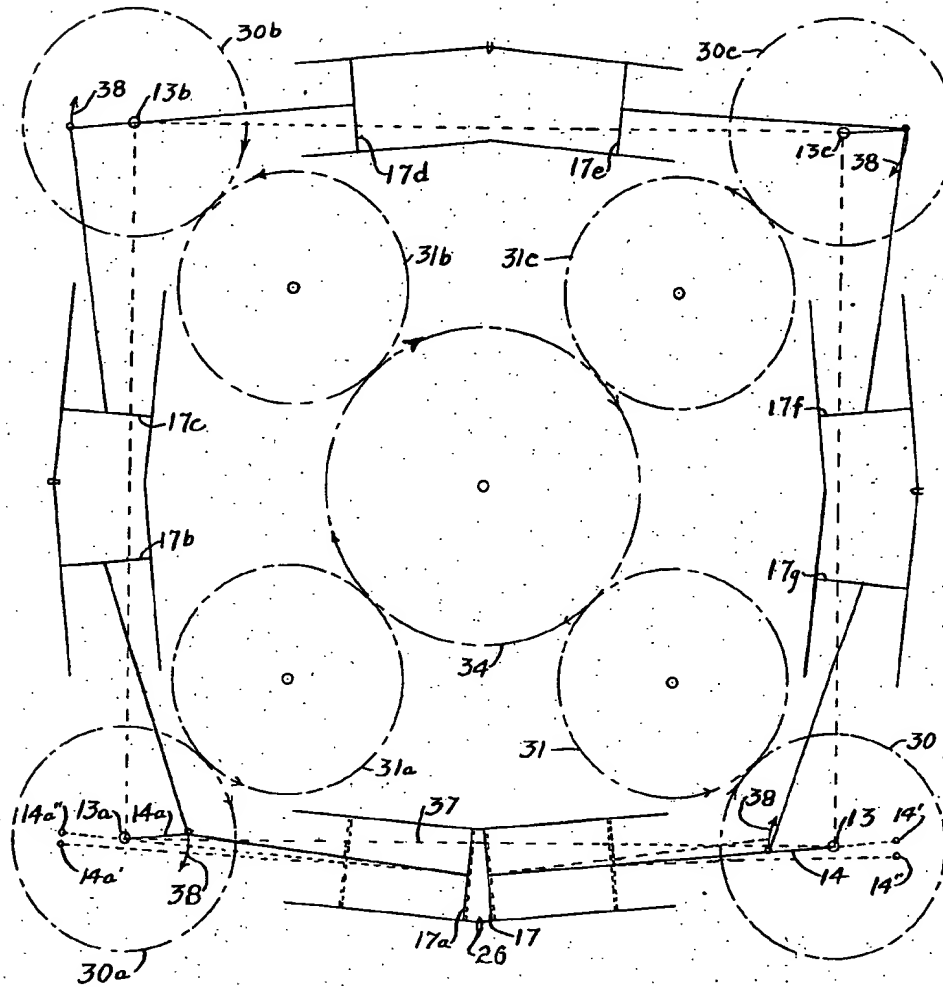


FIG. 15

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UNITED STATES PATENT OFFICE

2,355,379

MULTIPLE PISTON ENGINE

Alfred C. Johnson, Santa Clara, Calif.

Application February 1, 1943, Serial No. 474,395

3 Claims. (Cl. 123—51)

It is one object of the present invention to provide multiple piston engines that will be much more efficient in the production of power from low grade and cheap fuel than those engines heretofore known.

It is another object to provide an engine of the character indicated wherein two opposed pistons cooperate in the formation of a combustion chamber common to both of them and are timed to secure a more efficient inlet of air and exhaustion of burnt gases in the cylinder in which they operate. Still another object of the invention is to provide a smoother flow of power to the driven shaft than can be obtained with this type of engine as heretofore produced.

It is also an object of the invention to provide an engine of the character indicated wherein the weight per horsepower is reduced to the lowest practicable point, and one that is simple and economical in construction, that may be easily and quickly assembled, disassembled or repaired, and highly efficient in its practical application.

In the drawing:

Figure 1 is a side elevation of an engine embodying my invention with parts broken away and partly in section.

Figure 2 is an end view of one-half of the engine.

Figure 3 is an end view of one-half of the engine with parts broken away and with a part in section at 3—3 of Figure 1.

Figure 4 is an outside elevation of one side of the engine block with part broken away.

Figure 5 is a sectional view of the engine block on line 5—5 of Figure 4.

Figure 6 is a sectional view on line 6—6, Figure 4.

Figure 7 is an enlarged cross section through the cylinder structure at the point of air inlet, parts broken away.

Figure 8 is an elevation of the same, parts being broken away.

Figure 9 is an enlarged cross section through the cylinder structure at the point of the exhaust ports, parts being broken away.

Figure 10 is a sectional view on line 10—10, Figure 9.

Figure 11 is an enlarged cross section through adjoining cylinders showing their mounting, parts broken away.

Figure 12 is a sectional view on line 12—12, Figure 11.

Figure 13 is an enlarged cross section through the center of a cylinder.

Figure 14 is a sectional view on line 14—14, Figure 13.

Figure 15 is a diagram showing the mode of operation of the engine.

The particular engine disclosed is built around a block comprising two symmetrically arranged identical castings as 1, and each casting is substantially rectangular in cross section and hollow as indicated by the partial section in Figure 5, the corners being formed at forty-five degrees to the sides. The inner ends of the two elements 1 are bolted together as at 2, and their outer ends are fitted with closures as 3. Each of the four sides of the member 1 is provided with 15 bosses as 4 and 5 and top and bottom flanges 6 and 7 provided with curvilinear seats as 8 and 9 for the purpose hereinafter described. Each pair of adjoining corner flanges as 8—8a and 9—9a has a semi-circular trough shaped member with 20 closed ends as 10—10a mounted thereon to complete housings for the several crank-shafts, and form chambers as 11 and 11a.

Mounted in suitable bearings as 12 in chamber 11 and extending from one end to the other of said chamber is a crank-shaft 13, and the structure here described is duplicated in each of the other corner chambers, the four crankshafts being located exactly at the four corners of a square and paralleling each other.

In the present instance each crank-shaft is 30 provided with six cranks as 14, and each crank has two piston-rods as 15 and 16 mounted thereon, the one straddling the other as shown.

Each piston-rod, as 15, is connected to a piston 35 17, and the piston is reciprocated in a cylinder 18. The cylinder 18 in two parts is seated in the aligned curvilinear seats 8 and 9 in flanges 6 and 7, and is firmly and slidably held in place in the following manner. The ends are held in place 40 by means of straps 19 secured to the bosses 4 and 5 by means of bolts 52, and the center is fixedly secured by means of a part 39 which terminates on both sides of the cylinder in a member 21 provided with a tangentially disposed groove 22. 45 Two adjacent cylinders are placed in position on seats 8—9 and with members 21 seated on a boss 4 after which bolts 23 are screwed into position and the cylinders are secured fixedly and firmly in place.

The cylinder 18 consists of two halves with 50 their open ends directed toward a crank-shaft as 13 and 13a, the longitudinal axis of the cylinder forming an obtuse angle with a straight line joining the centers of the two crankshafts. In 55 other words, the longitudinal axis of each half

of the cylinder forms an acute angle with said straight line, in the present instance lying at an angle of five degrees relative thereto.

The cylinder 18 is provided with air inlet ports at 24 and exhaust ports at 25 inclined toward the center of the cylinder and tangentially relative thereto, and in an opposite direction relative to each other so that air entering the ports 24 in one direction will exhaust with burnt gases while flowing in the same direction. The fuel injector points are indicated at 26, and the water jackets are indicated at 27. Water circulation past the intake ports 24 is provided by by-pass 28 and past the exhaust ports 25 by passages 29. The outside connections of the water jackets and the injector points are not shown.

On the center of each crank-shaft is mounted a gear 30, and this gear meshes with a similar gear 31 mounted on a shaft 32 in bearing 33 on block 1. Each gear 31 meshes with a central gear 34 on driven shaft 35 mounted in bearings as 36 and extending axially relative to the several banks of engines.

By means of this method of construction all of the working parts except the gears and their supports are located exteriorly of the engine block and are readily accessible. Furthermore, the angular form of the double cylinder results in the formation of a combustion chamber, when the two pistons are furthest advanced, that is wedge-shaped from front to rear so that when compression takes place and the fuel is injected the turbulence effected by the angular entrance of the air is maintained, or probably increased, with a resulting perfect mixing of the air and fuel.

In the diagram 37 indicates a straight line joining the centers of the two crank-shafts 13 and 13a and the crank 14 is at top dead center before it reaches the line 37, all of the cranks turning in the direction indicated by the arrows 38. The crank 14a at this moment is in the position shown just before it reaches the line 37 so that when it passes the line 37 to its top dead center and advances the face of its piston 17a to the position indicated by the dotted line the crank 14, moving exactly the same distance in the same time has also passed the line 37 and drawn the face of the piston 17 back to the position indicated by the dotted line. The same overlapping of the strokes of the two pistons also takes place at the other end of their strokes; that is, while the crank 14 moves low dead center at 14' to 14'' and correspondingly advances the face of its piston as indicated in dotted lines the crank 14a moves from 14a' to bottom dead center 14a'' 35

and withdraws the face of its piston as indicated in dotted lines. This action means that piston 17 moves to compression slightly in advance of piston 17a and consequently effects a more perfect scavenging of burnt gases before the admission of air than otherwise would be the case, and its slight advance over piston 17a on expansion permits a slightly earlier discharge of burnt gases before the admission of air.

When the pistons 17 and 17a are in the positions shown in solid lines in the diagram, the pistons 17b, 17c, 17d, 17e, 17f and 17g are in the positions shown, pistons 17b and 17c, 17d and 17e, 17f and 17g, all working in pairs in the same identical manner as pistons 17 and 17a, the power from all of them being transmitted to the central shaft 35. This set of four crank-shafts and their connections are referred to as one bank, and with an assembly of six banks a practically continuous and smooth flow of power is applied to the driven shaft.

The central portion of the cylinder 18 is a separate element shown at 39 and fitted to the cylinder end portions as shown at 40, but enlarged to form seats as 41 for the water jackets 27 and having water passages 42 formed therethrough.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent, is:

1. An engine comprising, a block having parallel cylinders disposed thereon and provided with a boss between each two cylinders, adjoining cylinders being provided with opposed elements formed with registering grooves and disposed to seat on the intervening boss, and means engaging said grooves and boss to fixedly hold the cylinders in position.

2. An engine comprising, a block having parallel cylinders disposed thereon and provided with a boss between each two cylinders, adjoining cylinders being provided with opposed elements formed with registering grooves and disposed to seat on the intervening boss, means engaging said grooves and boss to fixedly hold the cylinders in position, and means operatively disposed on the block to slidably support the ends of the cylinders.

3. An engine comprising, a supporting block having parallel cylinders open at both ends and having central explosion chambers mounted thereon, means operative to rigidly support the central portion of each cylinder, and means operative to slidably support the two ends of each cylinder.

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United States Patent [19]

Lemp

[11] Patent Number: 4,836,246

[45] Date of Patent: Jun. 6, 1989

[54] MANIFOLD FOR DISTRIBUTING A FLUID
AND METHOD FOR MAKING SAME

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[73] Assignee: Colt Industries Inc., New York, N.Y.

[21] Appl. No.: 80,990

[22] Filed: Aug. 3, 1987

[51] Int. CL⁴ F23K 5/00

[52] U.S. CL 137/561 A

[58] Field of Search 137/561 R, 562 A

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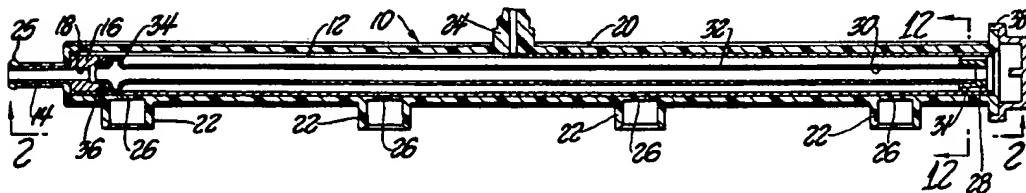
Primary Examiner—John Rivell

Attorney, Agent, or Firm—Walter Potoroka, Sr.

[57] ABSTRACT

A manifold for distributing a fluid to a plurality of fluid ports, and a method for manufacturing the manifold. The manifold comprises a first tubular means forming a first tube, a second tubular means forming a second tube extending axially outwardly beyond said first tubular means, support means connected to one end of said first tubular means for supporting said second tubular means in spaced relationship to said first tubular means, and housing means molded about said first and second tubular means for forming an integral manifold.

34 Claims, 4 Drawing Sheets



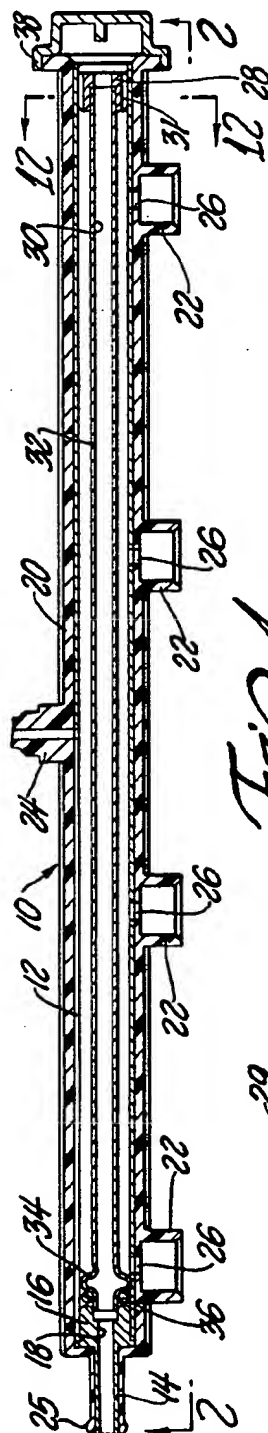


Fig. 1

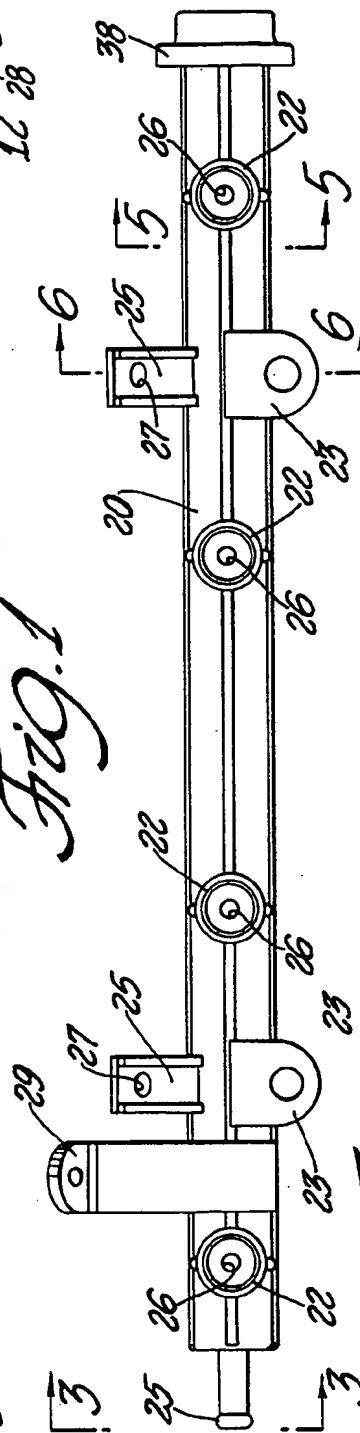


Fig. 2

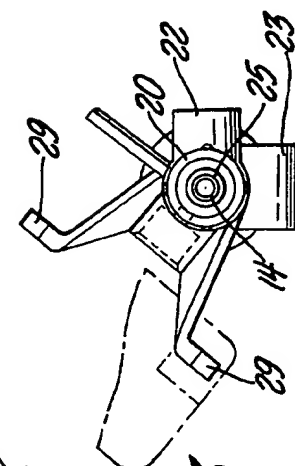


Fig. 3



Fig. 12

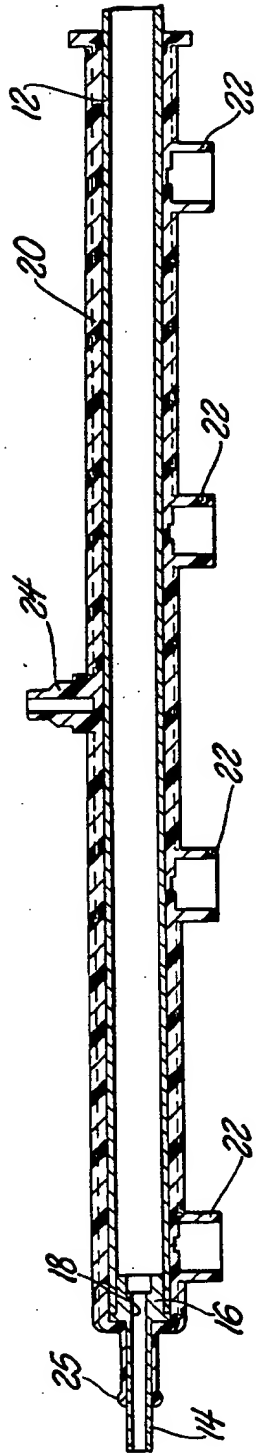


Fig. 4

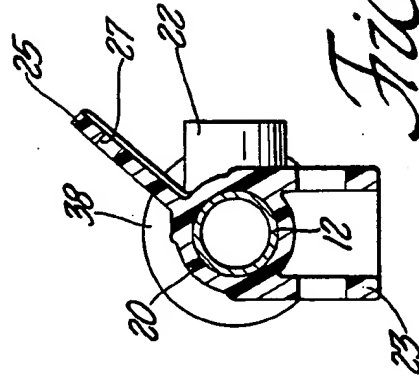


Fig. 6

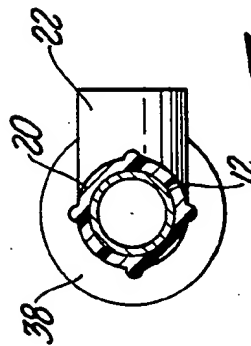


Fig. 5

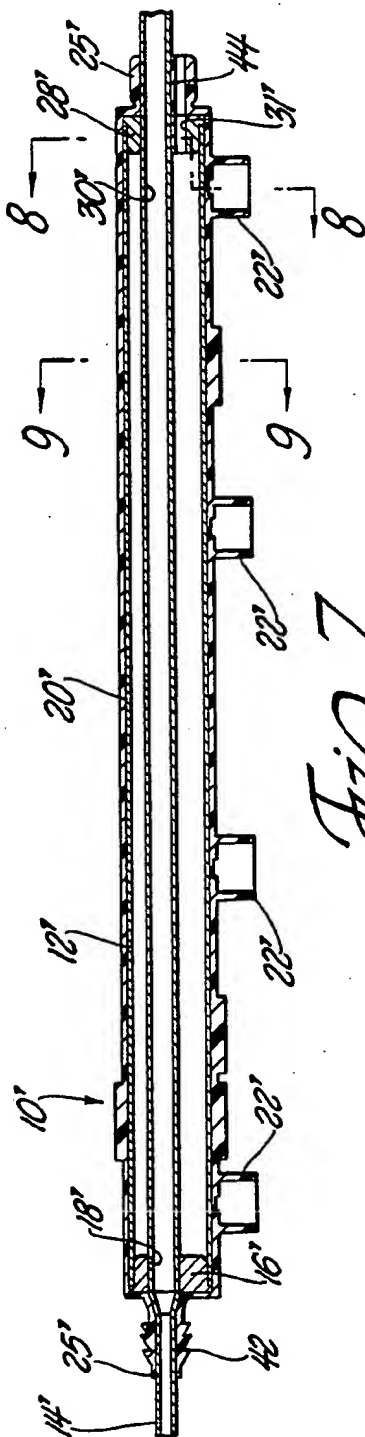


Fig. 7

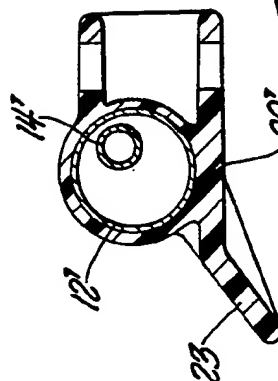


Fig. 8

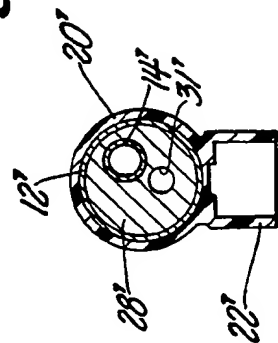


Fig. 9

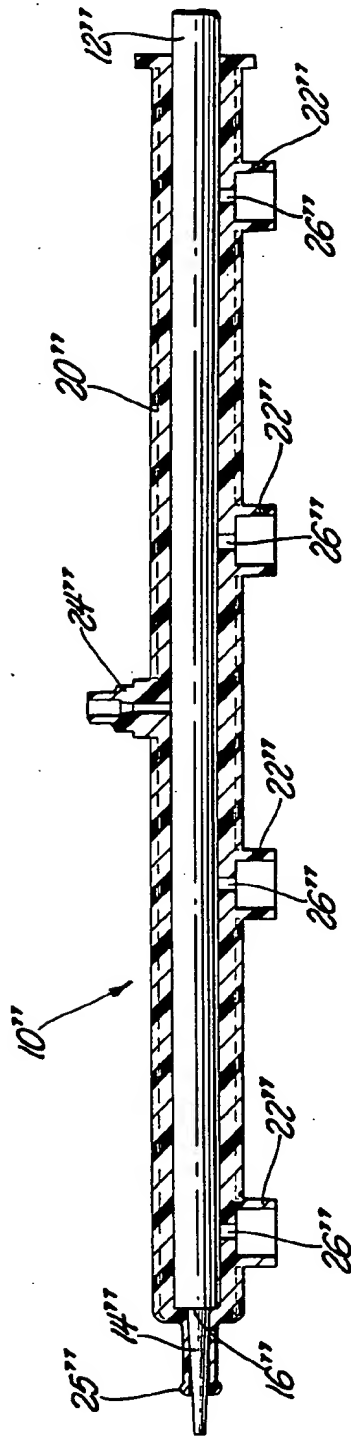


Fig. 10

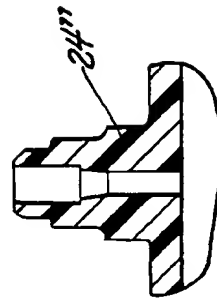


Fig. 11

MANIFOLD FOR DISTRIBUTING A FLUID AND METHOD FOR MAKING SAME

TECHNICAL FIELD

The subject invention relates to a manifold for distributing a fluid to a plurality of fluid ports, and particularly, a fuel rail for distributing fuel to a plurality of fuel injectors in an engine.

BACKGROUND ART

Manifolds for distributing fuel to a plurality of fuel injectors have been used in the past. Typically, a fuel rail or manifold comprises a longitudinal tube and a plurality of fuel cups spaced longitudinally therealong. The manifold also includes several bracket members for connecting the manifold to an engine.

The problem with such manifolds is that the longitudinal tube, fuel cups and brackets are separate members. This requires each part to be individually machined to the proper dimensions and then assembled in a fixture. Brazing is used to secure all the part together as an integral unit. This requires a large amount of time and is very costly to produce.

STATEMENT OF THE INVENTION AND ADVANTAGES

A manifold for distributing a fluid to a plurality of fluid ports includes a first tubular means forming a first tube. A second tubular means forms a second tube extending axially outwardly beyond said first tubular means. A support means connected to one end of the first tubular means supports the second tubular means in spaced relationship to the first tubular means. A housing means is molded about the first and second tubular means for forming an integral manifold.

Accordingly, a method for making a manifold for distributing fluid to a plurality of fluid ports includes the steps of forming a first tube. The steps include forming a second tube to extend axially beyond the first tube. The second tube is supported in spaced relationship to the first tube by an end plug connected to one end of the first tube. The ends of the tubes are secured in a die and the material is injected into the die. An integral housing is formed about the tubes and has at least one fluid port connection for attachment to fluid port and bracket support members to allow attachment to a support surface.

The subject invention forms the longitudinal housing including the fuel cups and support brackets as an integral manifold. This saves time and is less costly than forming individual parts and brazing them together.

FIGURES IN THE DRAWINGS

Other advantages of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

FIG. 1 is a sectional elevational view of one embodiment of the subject invention;

FIG. 2 is a bottom view of the subject invention, taken along the plane of line 2—2 of FIG. 1, looking in the direction of the arrows;

FIG. 3 is an elevational view taken along lines 3—3 of FIG. 2, looking in the direction of the arrows;

FIG. 4 is a sectional elevational view of the preferred embodiment of the subject invention;

FIG. 5 is a sectional view of the subject invention taken along lines 5—5 of FIG. 2, looking in the direction of the arrows;

FIG. 6 is a sectional view taken along lines 6—6 of FIG. 2, looking in the direction of the arrows;

FIG. 7 is a sectional elevational view of a first alternate embodiment of the subject invention;

FIG. 8 is a sectional view of the first alternate embodiment taken along lines 8—8 of FIG. 7, looking in the direction of the arrows;

FIG. 9 is a sectional view of the alternate first embodiment taken along lines 9—9 of FIG. 7;

FIG. 10 is a sectional view of a second alternate embodiment of the subject invention;

FIG. 11 is an enlarged fragmentary sectional view of the valve boss of FIG. 10; and

FIG. 12 is a sectional view taken along lines 12—12 of FIG. 1, looking in the direction of the arrows.

DETAILED DESCRIPTION OF THE DRAWINGS

A fuel rail or manifold for distributing a fuel or fluid to a plurality of fuel cups or ports is generally shown at 10 in FIG. 1. The manifold 10 includes a first tubular means 12 comprising a first longitudinal tube 12 having an open end at each end thereof. The manifold 10 includes a second tubular means 14 comprising a second longitudinal tube 14 extending axially outwardly beyond the first tubular means 12. The manifold 10 further includes a support means 16 connected to one end of the first tubular means 12 for supporting the second tubular means 14 in spaced relationship to the first tubular means 12. The support means 16 comprises a first end plug 16 disposed in one end of the first tube 12 and having a first aperture 18 communicating axially therethrough. One end of the second tube 14 is connected to or may be formed integrally with one end of the first end plug 16.

The manifold 10 includes a housing means 20 comprising a polymer material molded about the first 12 and second 14 tubular means for forming an integral housing 20 about the tubular means 12, 14 to form an integral manifold 10. The housing 20 includes at least one, and preferably a plurality of longitudinally spaced, fluid cup or port connections 22 integrally formed with and along the housing means 20 for attachment to a fuel injector of fluid port (not shown). As illustrated in FIGS. 2, 3 and 6, the housing means 20 also includes bracket support members 23 formed integrally with the housing means 20 to allow attachment to a support surface. The housing 20 also includes pressure regulator mounting brackets 29 to allow attachment of a pressure regulator to the housing 20. The housing means 20 further includes a pressure valve boss 24 formed integrally with the housing 20 and having a configuration similar to a nipple which may be threaded. The housing means 20 also includes an end connection 25 integrally formed with the housing means 20 about the second tubular means 14. The end connection 25 may have a plurality of barbs or be threaded. The housing means 20 includes wire support members 25 having an aperture 27 to allow injector wires (not shown) to be secured to support members 25.

The manifold 10 also includes an aperture means 26 forming at least one second aperture 26 in the fluid port connection 22 and communicating with the housing

means 20 and the first tubular means 12 to allow fluid to flow from the first tubular means 12 to the fluid port connection 22. The manifold 10 further includes a second end plug or spacer 28 disposed in the other end of the first tube 12 and having a third aperture 30 communicating therethrough. As illustrated in FIG. 12, the second end plug 28 includes a plurality of grooves 31 in the outer periphery thereof to allow fuel to pass from the second tubular means 14 to the first tubular means 12. A third tube 32 communicates with the second tube 14 and has an annular ridge 34 formed therein and spaced axially from one end thereof. The third tube 32 is disposed within the first tube 12 and has one end communicating with the second tube 14 and the other end communicating with the second end plug 28. The end plugs 16, 28 have one end disposed about the third tube 32 and within the first tube 12 to space the third tube 32 within the first tube 12. A sealing member such as an O-ring 36 is disposed about the third tube 32 and axially between the ridge 34 and the first end plug 16. The manifold 10 includes an end cap 38 connected to one end of the housing means 20 to form a closed end thereof. The third tube 32, O-ring 36 and second end plug 28, which may be inserted into the first tubular means 12 prior to attaching end cap 38, is an optional structure that provides optimum performance. Thus, the manifold 10 may be adapted to a variety of internal structures.

In operation, fluid such as fuel enters the manifold 10 through the second tubular means 14. Fuel flows from the second tubular means 14 and through the third tube 32 to the end cap 38. Fuel exits the end cap 38 through grooves 31 in the second end plug 28 and into the first tubular means 12. Fuel then flows from the first tubular means 12 through apertures 26 and into the fuel cup connections 22.

A first alternative embodiment of the subject invention wherein like parts are identified by like numerals having a prime numeral is generally shown at 10' in FIG. 7. The manifold 10' includes the second tubular means 14' comprising a second tube 14' disposed within the first aperture 18' of the first end plug 16' and extending along the entire length of the first tube 12' in spaced relationship thereto and axially outwardly beyond both ends of the first tube 12'. The second tubular means 14' may be concentric or eccentric with the first tubular means 12' as illustrated in FIGS. 8 and 9. The housing means 20' includes an end connection 25' integrally formed with the housing means 20' at each end thereof about the second tube 14'. One of the end connections 25' may have barbs 42 integrally formed thereabout. The other end connection 25' may be threaded 44.

A second alternate embodiment of the subject invention wherein like parts are identified by like numerals having a double prime numeral is generally shown at 10'' in FIGS. 10 and 11. The manifold 10'' is made entirely out of plastic. In other words, a core insert 12'', 14'', 16'' is pulled out of the housing means 20'' after molding, thereby eliminating the first and second tubular means and first end plug. However, metal inserts (not shown) may be inserted within the housing means 20'' if necessary to strengthen the manifold 10''.

Accordingly, the subject invention includes a method for making a manifold for distributing a fluid to a plurality of fluid ports including the steps of forming a first tube 12. The steps include forming a second tube 14 to extend axially beyond the first tube 12. The steps include supporting the second tube 14 in spaced relation-

ship to the first tube 12 by a first end plug 16 connected to one end of the first tube 12.

The step of supporting includes pressing a first end plug 16 about one end of the second tube 14. The steps include pressing the first tube 12 about the first end plug 16 so that one end of the first tube 12 is substantially flush with a flange on the first end plug 16. The steps further include securing the ends of the tubes 12, 14 in a die at approximately 0.625 inches at each end thereof and injecting a material into the die such as between two mold halves for conventional injection molding. The steps further include forming an integral housing 20 about the tubes 12, 14 having at least one fluid port connection 22 for attachment to a fluid port, wire support members 25 to support injector wires and bracket support members 23 to allow attachment of the manifold 10 to a support surface as illustrated in FIGS. 4 through 6. The steps include spacing the second tube 14 concentric or eccentric with the first tube 12 by the end plugs 16, 28.

The method includes the steps of cutting off the ends of the tubes 12, 14 flush with the housing 20 at each end thereof. The steps also include machining an aperture 26 in the fluid port connection 22 to communicate with the first tube 12 to allow fluid to flow from the first tube 12 to the fluid port connection 22, which is formed to a predetermined diameter or size by molding or machining. The steps also include machining the internal diameter of an aperture in the pressure valve boss 24 to a predetermined diameter and to communicate with the first tube 12. The steps further include machining a configuration 42, 44 on either end of the housing 20.

The steps also include forming the housing 20 of a suitable thermoplastic or thermoset material. The steps include inserting internal parts 28, 32, 36 into the first tube 12 through the open end thereof. The steps include sonic or electromagnetically welding an end cap 38 about the open end of the housing 20.

As illustrated in FIGS. 7 through 9, a first alternate method of making the first alternate embodiment 10' of the subject invention includes the steps of forming the second tube 14' to extend along the entire length and axially beyond both ends of the first tube 12' in spaced relationship thereto by a first end plug 16'. The steps also include inserting a second end plug 28' about the second tube 14' and within the first tube 12' at the other end thereof before inserting the tubes 12', 14' in the die. The remaining machining steps are similar to those of the method of the preferred embodiment 10.

A second alternate method of making the second alternate embodiment 10'' of the subject invention as illustrated in FIG. 10 and 11 includes the steps of forming the first 12'' and second 14'' tubes and first end plug 16'' as an integral unit such as a core insert. The tubes 12'', 14'', 16'' have a taper along the length thereof. The one-piece core insert 12'', 14'', 16'' is inserted and secured at both ends in the die. The housing 20'' is molded or formed about the core insert 12'', 14'', 16''. After the housing 20'' is formed or molded, the core insert 12'', 14'', 16'' is pulled from one end and removed from the housing 20''. Thus, an all plastic manifold 10'' is formed without inner metal tubes. The remaining machining steps are similar to those of the method of the preferred embodiment 10.

The invention has been described in an illustrative manner, and it is to be understood that the terminology which has been used is intended to be in the nature of words of description rather than of limitation.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is, therefore, to be understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A manifold for distributing a fluid to a plurality of fluid ports, said assembly comprising:

a first tubular means forming a first tube comprising a first tube;

a second tubular means forming a second tube extending axially outwardly beyond said first tubular means;

support means connected to one end of said first tubular means for supporting said second tubular means in spaced relationship to said first tubular means;

housing means molded about said first and second tubular means for forming an integral manifold, said housing means including at least one fluid port connection integrally formed with and along said housing means for attachment to a fluid port and an aperture means forming at least one aperture in said fluid port connection and communicating with said housing means and said first tubular means to allow fluid to flow from said first tubular means to said fluid port connection, bracket supply members formed integrally with said housing means to allow attachment to a support surface, said support means comprising a first end plug disposed in one end of said first tube and having a first aperture communicating axially therethrough.

2. A manifold as set forth in claim 1 characterized by said second tubular means comprising a second tube disposed within said first aperture of said first end plug and extending along the entire length and axially beyond the other end of said first tube in spaced relationship thereto.

3. A manifold as set forth in claim 2 characterized by said support means including a second end plug disposed in the other end of said first tube and having a second aperture communicating therethrough, said second tube being disposed in said second aperture.

4. A manifold as set forth in claim 3 including an end connection integrally formed with said housing means at each end thereof.

5. A manifold as set forth in claim 4 characterized by one of said end connections having barbs integrally formed thereabout.

6. A manifold as set forth in claim 5 characterized by the other of said end connections being threaded.

7. A manifold as set forth in claim 1 characterized by said second tubular means comprising a second tube having one end connected to said support means.

8. A manifold as set forth in claim 7 characterized by said support means comprising a first end plug having a continuous passage communicating axially therethrough to said end of said second tubular means.

9. A manifold as set forth in claim 8 including an end cap connected to one end of said housing means to form a closed end thereof.

10. A manifold as set forth in claim 9 including a pressure valve boss formed integrally with said housing means.

11. A manifold as set forth in claim 10 characterized by said first and second tubes and said support means being formed as an integral unit.

12. A manifold as set forth in claim 10 or 11 characterized by said housing means comprising a polymer material.

13. A manifold for distributing a fluid to a plurality of fluid ports, said assembly comprising;

a first tubular means forming a first tube having an open end at each end thereof, a second tubular means forming a second tube extending axially outwardly beyond said first tubular means, support means connected to one end of said first tubular means for supporting said second tubular means in spaced relationship to said first tubular means, housing means molded about said first and second tubular means for forming an integral manifold, at least one fluid port connection integrally formed with and along said housing means for attachment to a fluid port, aperture means forming at least one aperture in said fluid port connection and communicating with said housing means and said first tubular means to allow fluid to flow from said first tubular means to said fluid port connection, bracket support members formed integrally with said housing means to allow attachment to a support surface, said first tubular means comprising a first tube, said support means comprising a first end plug disposed in one end of said first tube and having a first aperture communicating axially therethrough, said second tubular means comprising a second tube disposed within said first aperture of said first end plug and extending along the entire length and axially beyond the other end of said first tube in spaced relationship thereto, said support means including a second end plug disposed in the other end of said first tube and having a second aperture communicating therethrough, and including an end connection integrally formed with said housing means at each end thereof, one of said end connections having barbs integrally formed thereabout and the other said end connection being threaded.

14. A manifold for distributing a fluid to a plurality of fluid ports, said assembly comprising;

a first tubular means forming a first tube having an open end at each end thereof, a second tubular means forming a second tube extending axially outwardly beyond said first tubular means, support means connected to one end of said first tubular means for supporting said second tubular means in spaced relationship to said first tubular means, housing means molded about said first and second tubular means for forming an integral manifold, at least one fluid port connection integrally formed with and along said housing means for attachment to a fluid port, aperture means forming at least one aperture in said fluid port connection and communicating with the said housing means and said first tubular means to allow fluid to flow from said first tubular means to said fluid port connection, bracket support members formed integrally with said housing means to allow attachment to a support surface, said first tubular means comprising a first tube, said second tubular means comprising a second tube having one end connected to said support means, said support means comprising an end plug having a continuous passage communicating axially therethrough to said end of said second tubular means, an end cap connected to one end of said housing means to form a closed end thereof, a pressure valve boss formed integrally with said housing

means, and said housing means comprising a polymer material.

15. A method for making a manifold for distributing fluid to a plurality of fluid ports, said method comprising the steps of:

forming a first tube;

forming a second tube to extend axially beyond the first tube;

supporting the second tube in spaced relationship to the first tube by an end plug connected to one end of the first tube;

securing the ends of the tubes in a die; and

injecting a material into the die and forming an integral housing about the tubes having at least one fluid port connection for attachment to a fluid port and bracket support members to allow attachment to a support surface.

16. A method as set forth in claim 15 including the step of cutting off the ends of the tubes flush with the housing at each end thereof.

17. A method as set forth in claim 16 including the step of machining an aperture in the fluid port connection to communicate with the first tube to allow fluid to flow from the first tube to the fluid port connection.

18. A method as set forth in claim 17 including the step of forming the fluid port connection of the housing to a predetermined diameter.

19. A method as set forth in claim 18 characterized by the step of forming the housing of a polymer material.

20. A method as set forth in claim 19 including the step of machining a configuration on either end of the housing.

21. A method as set forth in claim 20 including the step of inserting internal parts into the first tube through the open end thereof.

22. A method as set forth in claim 21 including the step of welding an end cap about the open end of the housing.

23. A method as set forth in claim 15 including the step of spacing the second tube concentric with the first tube.

24. A method as set forth in claim 15 including the step of spacing the second tube eccentric with the first tube.

25. A method as set forth in claim 15 including the step of forming the second tube to extend along the entire length and axially beyond the other end of the first tube in spaced relationship thereto.

26. A method as set forth in claim 25 including the step of pressing an end plug about one end of the second tube.

27. A method as set forth in claim 26 including the step of pressing the first tube about the first end plug so that one end of the first tube is substantially flush with a flange on the end plug.

28. A method as set forth in claim 27 including the step of inserting a second end plug about the second tube and within the first tube at the other end thereof.

29. A method as set forth in claim 9 including the step of removing the first and second tubes and end plug after the housing is molded.

30. A method as set forth in claim 29 further characterized by forming the first and second tubes and end plug as an integral unit.

31. A method as set forth in claim 30 further characterized by forming a taper on the first and second tubes.

32. A method for making a manifold for distributing a fluid to a plurality of fluid ports, said method comprising the steps of:

forming a first tube having an open end at each end thereof, forming a second tube to extend axially

beyond the first tube, supporting the second tube in spaced relationship to the first tube by a first end plug connected to one end of the first tube, securing the ends of the tubes in a die, injecting a material into the die and forming an integral housing about the tubes having at least one fluid port connection for attachment to a fluid port and bracket support members to allow attachment to a support surface, machining an aperture in the fluid port connection to communicate with the housing and first tube to allow fluid to flow from the first tube to the fluid port connection, cutting off the ends of the tubes flush with the housing at each end thereof, forming the fluid port connection of the housing to a predetermined diameter, machining a configuration on either end of the housing, spacing the second tube with respect to the first tube, forming the second tube to extend along the entire length and axially beyond the other end of the first tube in spaced relationship thereto, pressing an end plug about one end of the second tube, pressing the first tube about the end plug so that one end of the first tube is substantially flush with the flange on the end plug, inserting a second end plug about the second tube and within the first tube at the other end thereof, and machining a configuration in the pressure valve boss to a predetermined diameter.

33. A method for making a manifold for distributing a fluid to a plurality of fluid ports, said method comprising the steps of:

forming a first tube having an open end at each end thereof, forming a second tube to extend axially beyond the first tube, supporting the second tube in spaced relationship to the first tube by a first end plug connected to one end of the first tube, securing the ends of the tubes in a die, injecting a material into the die and forming a one-piece integral housing about the tubes having at least one fluid port connection for attachment to a fluid port and bracket support members to allow attachment to a support surface, machining an aperture in the fluid port connection to communicate with the housing and first tube to allow fluid to flow from the first tube to the fluid port connection, cutting off the ends of the tubes flush with the housing at each end thereof, forming the fluid port connection of the housing to a predetermined diameter, forming the housing of a polymer material, inserting internal parts into the first tube through the open end thereof, and welding an end cap about the open end of the housing.

34. A method for making a manifold for distributing a fluid to a plurality of fluid ports, said method comprising the steps of:

forming a first tube having an end plug at one end thereof and a second tube to extend axially beyond the first tube as an integral unit; forming a taper on the first and second tubes;

securing the ends of the tubes in a die;

injecting a material into the die and forming an integral housing about the tubes having at least one fluid port connection for attachment to a fluid port and bracket support members to allow attachment to a support surface;

removing the first and second tubes and end plug from the housing after the housing is molded; and machining an aperture in the fluid port connection to communicate with the housing to allow fluid to flow from within the housing to the fluid port connection.

* * * * *

[54] THIN FILM FORMING APPARATUS

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[30] Foreign Application Priority Data

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[51] Int. Cl.⁵ C23C 16/48

[52] U.S. Cl. 118/723; 118/715;
118/725

[58] Field of Search 118/715, 723, 725

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Primary Examiner—Richard Bueker

Attorney, Agent, or Firm—Flynn, Thiel, Boutell & Tanis

[57] ABSTRACT

A thin film forming apparatus includes, in addition to a material gas nozzle, a control gas nozzle for jetting a control gas flow which encircles a material gas flow jetted from the material gas nozzle against a substrate supported in a reaction chamber, so as to shape the material gas flow into the form of a beam.

7 Claims, 5 Drawing Sheets

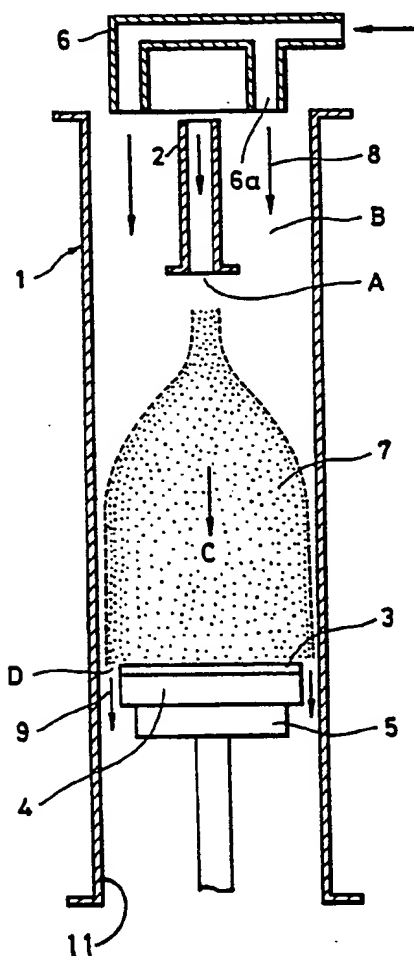


FIG. 1A

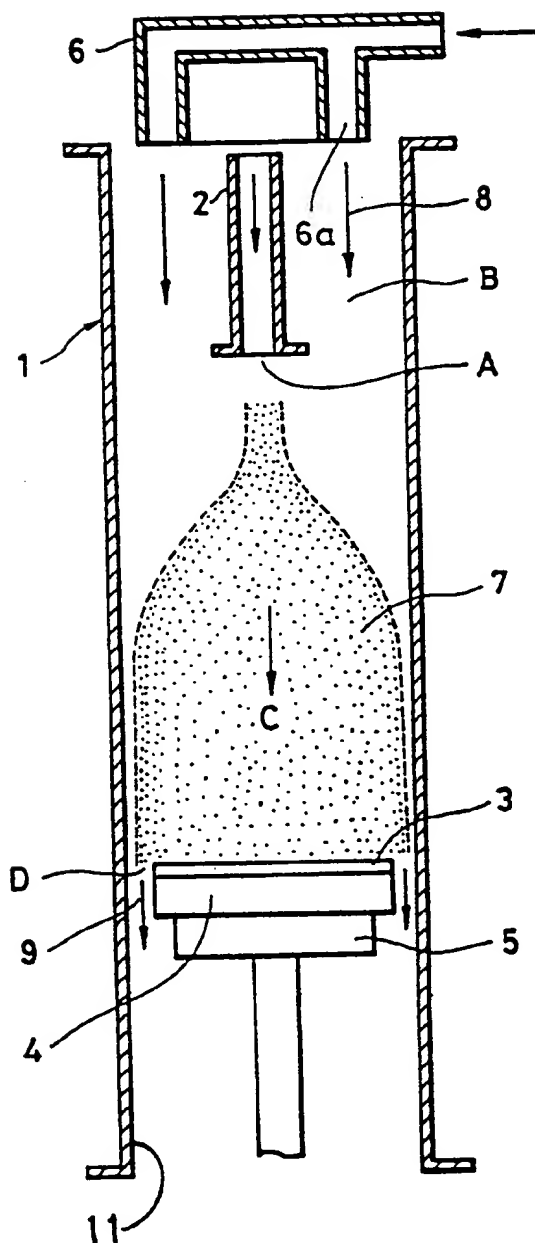


FIG. 1B

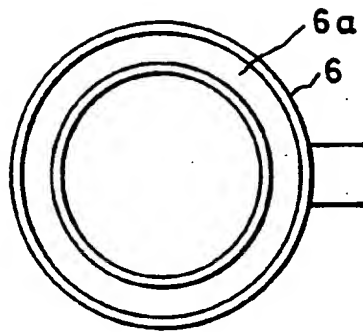


FIG. 1C

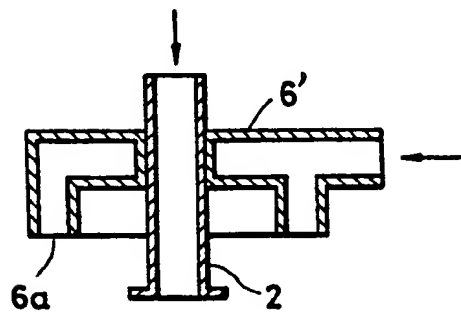


FIG. 1D

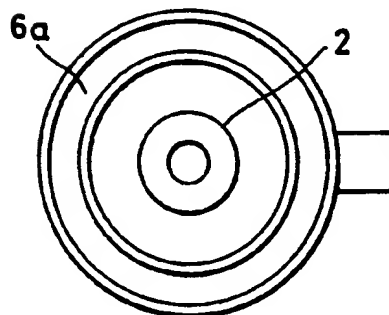


FIG. 2

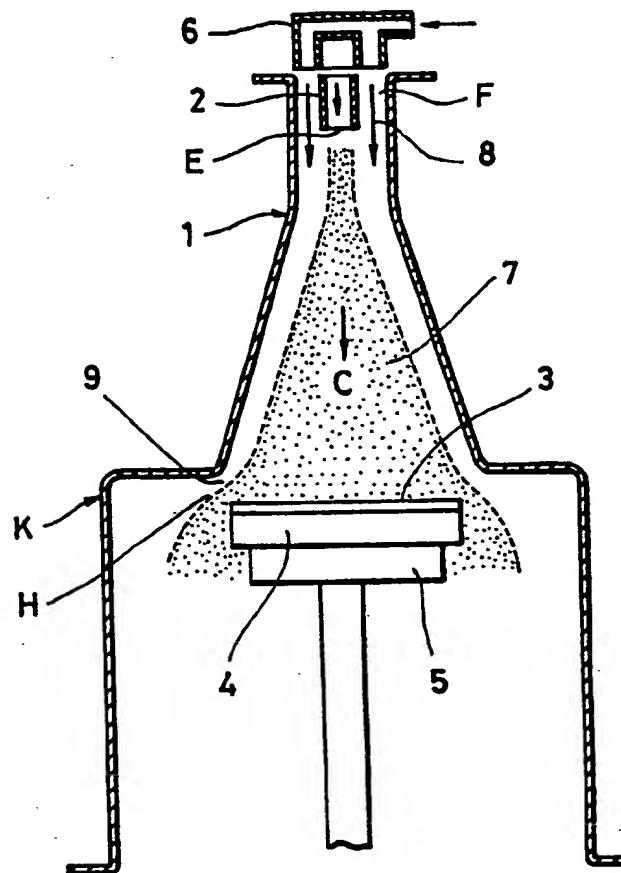


FIG. 3

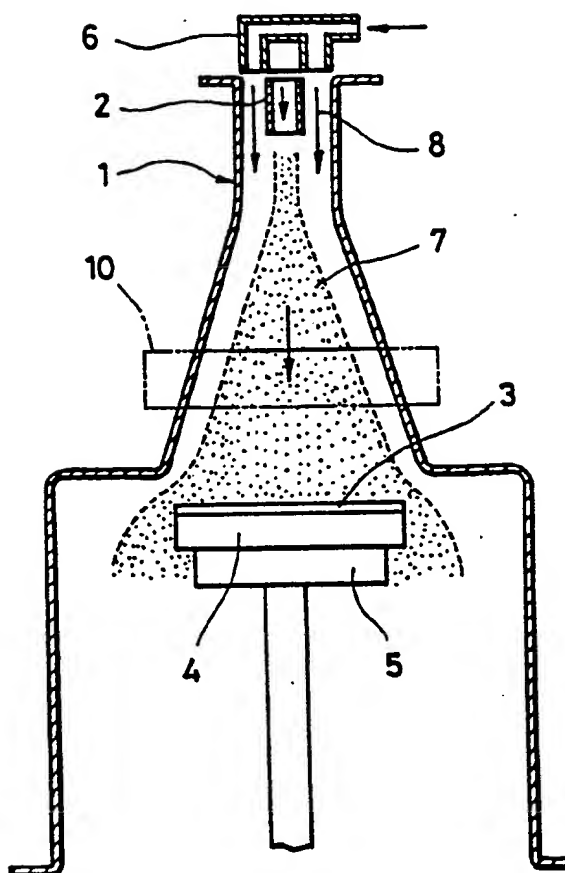


FIG. 4
PRIOR ART

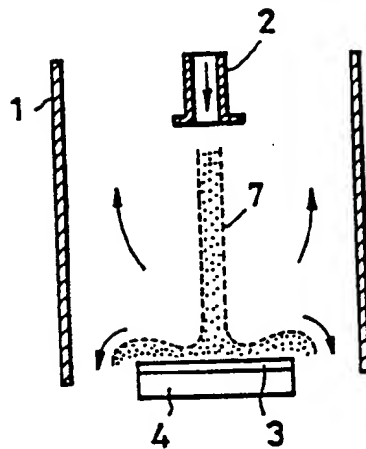


FIG. 5
PRIOR ART

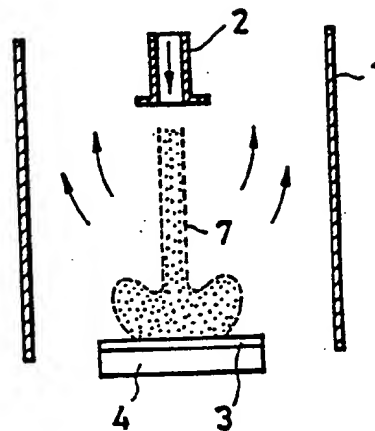


FIG. 6
PRIOR ART

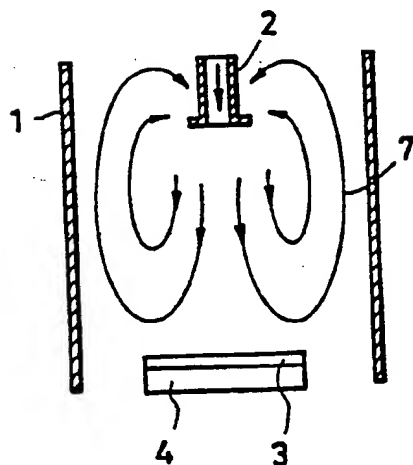
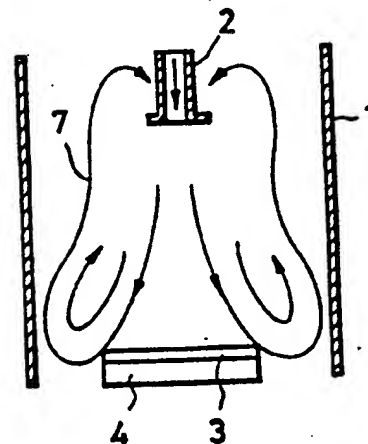


FIG. 7
PRIOR ART



THIN FILM FORMING APPARATUS

FIELD OF THE INVENTION

This invention relates to a thin film forming apparatus, and more particularly to an improvement of such a thin film forming apparatus using a chemical vapor deposition.

BACKGROUND OF THE INVENTION

A thin layer forming apparatus using a chemical vapor deposition (abbreviated "CVD process") is known in the field of electronics as one of apparatuses for forming a thin layer on a substrate.

The CVD method, which is a composing method utilizing a chemical reaction, is appreciated to be a suitable method for forming a high quality thin film not easily damaged and having a good step-covering property as compared to a physical deposition process such as vacuum deposition and sputtering. Further, as compared to an MBE (molecular beam epitaxy) process requiring a high vacuum, the CVD process, not requiring such a high vacuum, can use an inexpensive apparatus and is therefore suitable for mass-production.

However, there still exist some problems to be solved to provide a higher quality thin film using the CVD process. These problems are discussed below.

FIGS. 4 and 5 show gas flow patterns in a conventional thin film forming apparatus using the CVD process. In these drawings, reference numeral 1 refers to a reaction chamber, 2 to a nozzle for jetting material gas, 3 to a substrate, 4 to a heating susceptor for supporting and heating the substrate; 7 to a material gas flow from the nozzle 2.

FIG. 4 shows a pattern of the gas flow while the susceptor 4 is not heated and maintained at the ordinary room temperature (20° C.). The apparatus is designed so that the material gas flow appropriately reaches the substrate unless the susceptor is heated as referred to above. However, when the susceptor 4 is heated (400° C.) for promoting the chemical reaction, a turbulence occurs in the pattern of the material gas flow due to a heat convection. As a result, a desired supply is disabled, which causes deterioration in the quality of the deposited film such as disuniformity of the film, generation of pin holes in the film caused by nuclei produced in the gas phase.

There is recently proposed a CVD apparatus of a reduced pressure system as an improvement to remove the drawback of the normal pressure reaction system referred to above. This relies upon its property of suppressing the heat convection to reduce the pressure of the reaction chamber and reduce the ascending force.

FIGS. 6 and 7 show forms of the material gas flow under a reduced pressure.

In FIG. 6 which shows the gas flow 7 while the susceptor 4 is not heated and maintained at the ordinary room temperature (20° C.), circulating vortexes already occur. This is caused by the fact that since the speed of the material gas flow from the nozzle 2 is faster than that under the ordinary pressure and the bounce from the susceptor is rather large. In FIG. 7 which shows the gas flow 7 while the susceptor is heated (1000° C.), there are produced such large vortexes that the gas having reached a vicinity of the substrate on the susceptor soar again due to an additional ascending force caused by the heat convection.

As referred to above, turbulences in the material flow are not completely removed by merely reducing the pressure of the interior of the reaction chamber. Therefore, mere use of a reduced-pressure reaction chamber in the CVD apparatus cannot suppress turbulences in the material gas flow, and cannot prevent deterioration of the film quality caused by gas flow turbulences.

Further, since pressure reduction causes the material gas flow to expand throughout the reaction chamber, the material gas pollutes the reaction vessel, and the reaction vessel, in turn, pollutes the material gas.

Under these circumstances, for purposes of forming a high quality thin film in a reduced-pressure reaction system, it is indispensable to provide a new method capable of controlling the gas flow so that the material gas does not contact the wall of the reaction chamber.

OBJECT OF THE INVENTION

It is therefore an object of the invention to provide a thin film forming apparatus wherein no turbulence in the material gas flow is produced in a reduced pressure reaction system and the material gas never contacts wall surfaces of a reaction chamber.

SUMMARY OF THE INVENTION

According to the invention, there is provided a thin film forming apparatus comprising:

a material gas nozzle for jetting thin film forming material gas against a substrate supported in a reaction chamber in order to form a thin film on said substrate; and

a control gas nozzle disposed to encircle said material gas nozzle to jet a control gas flow for shaping a flow of said material gas from said material gas nozzle into the form of a beam.

In the thin film forming apparatus having the above-indicated arrangement, since the material gas flow jetted toward the substrate is shaped into a beam by another gas flow therearound, no turbulence caused by a heat convection occurs, and the material gas flow never contacts the wall surface of the reaction chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a view of an apparatus embodying the

FIG. 1B is a plan view of a gas nozzle;

FIG. 1C is a cross-sectional view of a control gas nozzle and a material gas nozzle;

FIG. 1D is a plan view of the nozzle of FIG. 1C;

FIGS. 2 and 3 are views of further embodiments of the invention;

FIGS. 4 and 5 are views for showing gas flow patterns in a conventional ordinary-pressure thin film forming apparatus; and

FIGS. 6 and 7 are views for showing gas flow patterns in a conventional reduced-pressure thin film forming apparatus.

DETAILED DESCRIPTION

FIGS. 1A and 1B are views of a thin film forming apparatus embodying the invention, and identify the same or similar elements to those in FIGS. 4 to 7 by the same reference numerals.

That is, reference numeral 1 refers to a reaction chamber, 2 to a nozzle for jetting material gas, 3 to a substrate, 4 to a heating susceptor, and 5 to a susceptor supporting table. Around the nozzle 2 is disposed a control gas nozzle 6 for jetting control gas so as to encircle the material gas flow jetted from the nozzle 2.

Although details of the material gas supply system, discharge system and control gas supply system are not shown, known systems are used for them. The nozzle 6, as shown in FIG. 1B, has a ring-shaped gas jet opening 6a disposed substantially concentrically of the nozzle 2. As shown in FIG. 1A, the nozzle 6 has a diameter corresponding to the width of the susceptor 4, and it is disposed radially outwardly of the nozzle 2. The reaction chamber 1 has a discharge outlet 11 which opens below the susceptor 4 and has a diameter larger than the width of the susceptor 4.

The material gas flow 7 jetted from the nozzle 2 against the substrate 3 is surrounded by the gas flow 8 jetted from the control gas nozzle 6 and is shaped into a beam. From here on, the material gas flow 7 is called a source flow and the control gas flow 8 is called a sheath flow for a better understanding of the inventive system.

The gas which forms the source flow 7 is material gas for growth of a CVD thin film. It may be any gas including silicon-based material gas such as SiH_4 , Si_2H_6 , etc. in case of forming a silicon-based thin film, or may be any gas including III-family material gas such as TM, TMG, etc. or mixture gas of V-family material gas such as AsH_3 and NH_3 the above-indicated V-family material gas in case of forming a III-V-family thin film. In case of forming a II-VI-family thin film, the material gas may be any gas including II-family material gas or mixture gas including VI-family material gas. In other words, the material gas may be any gas including a specific material of the film to be deposited on the substrate.

Preferable gas for forming the sheath flow 8 is, for example, H_2 gas, Ar gas or N_2 gas. In case of II-V and II-VI families, gas including V-family gas and gas including VI-family gas are acceptable, respectively. In any case, the sheath flow 8 prevents a turbulence in the flow caused by a jumping-back of the source flow 7.

In order to realize the gas flow control for the purposes referred to above, the following conditions are required.

First of all, the flow amount of the sheath flow 8 must be larger than that of the source flow 7. It is preferred for the sheath flow amount to be as large as several decade times the source flow amount.

In a specific example using a reaction chamber of about 60 mm ϕ , with displacement of 0.8 l/sec approximately under pressure of about 50 Torr, with the diameter of the susceptor being 54 mm ϕ approximately, the sheath flow was 3000 sccm and the source flow was 110 sccm.

In addition to the above-indicated requirement regarding the gas flow amounts, gas flow speeds in respective portion of the reaction chamber must be so established that the speed of the source flow at point A immediately after the jetting from the nozzle 2 is faster preferably by 1.5 to several times than the speed of the sheath flow at point B. The total flow speed at point C is substantially the same as that at point B. Further, it is necessary that the total flow speed passing through point D, i.e. a gap 9 defined between the reaction chamber and the susceptor, is much higher preferably by several to decade times than the flow speed at point C.

In a further specific example using the same reaction chamber of about 60 mm ϕ as referred to above, with displacement of 0.8 l/sec approximately under pressure of about 50 Torr, with the diameter of the susceptor being 54 mm ϕ approximately, the source flow speed at point A was 12 cm/sec approximately, the sheath flow speed at point B 9 cm/sec, the total flow speed at point

C 9 cm/sec approximately, and the total flow speed at point D in the gap 9 49 cm/sec approximately, respectively.

The pressure inside the reaction chamber may be varied as far as the source flow does not expand throughout the reaction chamber, it is sufficient to satisfy the relationship between the source flow amount and the sheath flow amount and the relationship between the flow speeds at points A, B, C and D.

According to the above-described gas flow control, no turbulence in the gas flow was produced even when the substrate is heated to about 1000° C. or more, and no contact of the material gas with the wall surface of the reaction chamber was recognized.

In particular, when the gap between the wall surface of the reaction chamber 1 and the susceptor 4 is narrowed to form the gap 9 as illustrated, the source flow of the material gas having reached the substrate surface is once expanded in a lateral direction, and subsequently speeded up at the position of the gap, so that it is swiftly sucked and evacuated into the gap. Therefore, the narrow gap 9 is effective in preventing a heat convection caused by the heat from the heated substrate.

FIGS. 1C and 1D show a modification of the embodiment of FIGS. 1A and 1B in which the nozzle 2 substantially concentrically penetrates a nozzle 6'.

FIG. 2 shows a further embodiment using a conical reaction chamber 1. This embodiment also requires that the sheath flow amount is larger than the source flow amount as in the embodiments in FIGS. 1A to 1D. Further, regarding the flow speed at respective portions of the reaction chamber, it is necessary that the flow speed of the material gas jetted from the nozzle 2 is faster at point E than the speed of the sheath flow at point F.

In this embodiment, using the conical reaction chamber, the total flow at point G is set to be slower than the speed at point F. As a result, the flow pattern of the source flow 7 does not include the shoulder (laterally expanding portion) which is present in the flow pattern of the source flow 7 of the embodiments of FIGS. 1A to 1D, and is smoothly extended in the form of a beam onto the substrate surface.

Also in the embodiment of FIG. 2, the reaction chamber is spread out laterally above the substrate 3 in order to ensure better suppression of the heat convection above the substrate. Further, the position of the substrate 3 can be adjusted by the susceptor supporting table 5 to vary the width of the gap 9. Therefore, the total flow speed at point H in the gap 9 can readily be adjusted, so that the excessive value of the speed at point H with respect to the total flow speed at point G may be adjusted at any time in accordance with the substrate temperature so as to establish a sufficient, appropriate value to effectively prevent the heat convection.

In a specific example using a reaction chamber which has the diameter of about 20 mm ϕ at a portion I, the length of about 70 mm in the straight cylindrical portion above the portion I, the tapered length of about 80 mm in the conical portion, the diameter of about 40 mm ϕ at the bottom of the conical portion and the diameter of about 10 mm ϕ of the enlarged cylindrical portion K, with displacement of about 0.4 l/sec under reduced pressure of about 100 Torr, with the source flow amount of 110 sccm and the sheath flow amount of 3000 sccm, the gas beam shown by a dotted line is established. Even when the substrate is heated to about 1000°

C. or more, no turbulence was produced in the gas flow, and no contact of the material gas to the reaction chamber was recognized.

FIG. 3 shows a plasma CVD apparatus incorporating the invention. This is substantially the same as the embodiment of FIG. 2 except that a plasma exciting portion 10 is provided. The plasma exciting portion 10 may use any selected one of high-frequency discharge, microwave discharge, ELR discharge, etc. Microwave discharge is preferable in pressure ranges where the source flow and the sheath flow can stably be formed.

When the gas flow is plasma-excited by the plasma discharge, pollution sources are generally increased by molecules, atoms, ions, electrons, active radicals, etc. in active gas which contact the wall surface of the reaction chamber. However, in the inventive arrangement configured to control the gas flow in the form of a beam, no turbulence occurs in the gas flow, and the material gas never contact the wall surface of the reaction chamber.

As described above, according to the inventive thin film forming apparatus, which effectively prevents a turbulence in the material gas flow and prevents contact between the material gas and the wall surface of the reaction chamber, ensures deposition of a high quality thin film.

What is claimed is:

1. A thin film forming apparatus of a pressure-reduced reaction type for forming a thin film on a substrate under a pressure reduced condition, comprising:
 - a reaction chamber;
 - substrate support means for supporting the substrate in said reaction chamber, said support means including a heating susceptor having an outer circumferential margin which is spaced by a gap from an inner wall surface of said reaction chamber;
 - a material gas nozzle which is located directly above said substrate and ejects a material gas flow into said chamber toward said substrate perpendicular to an upwardly facing major surface of said substrate; and
 - means for preventing said material gas flow from engaging walls of said chamber as it travels from

said material gas nozzle to said substrate, including a control gas nozzle which is disposed above said substrate and encircles said material gas nozzle, said control gas nozzle ejecting into said chamber a control gas flow which encircles said material gas flow and which forcibly re-orientates laterally expanding portions of said material gas flow in a direction toward said substrate;

wherein said chamber has a gas outlet on an opposite side of said susceptor from said material gas nozzle, said outlet having a diameter larger than the width of said susceptor, wherein said material gas flow at the exit of said material gas nozzle has a speed faster than that of said control gas flow adjacent thereto, and wherein the total gas flow passing through said gap has a speed faster than a speed of the total gas flow above said substrate.

2. The thin film forming apparatus according to claim 1, wherein said control gas nozzle has a jet opening in the form of a ring which is substantially concentric to said material gas nozzle.

3. The thin film forming apparatus according to claim 2, wherein said control gas nozzle has an outside diameter which is approximately equal to an outside diameter of said susceptor.

4. The thin film forming apparatus according to claim 11, wherein said reaction chamber has between said nozzles and said susceptor a portion of tapered cross section which gradually diverges in the gas flow direction.

5. The thin film forming apparatus according to claim 4, wherein said reaction chamber includes a small-diameter portion having said nozzles therein, and a large-diameter portion having said susceptor therein, said portion of tapered cross section extending between said small-diameter and large-diameter portions.

6. The thin-film forming apparatus according to claim 5, wherein the position of said susceptor within said chamber is vertically adjustable.

7. The thin film forming apparatus according to claim 1, further comprising means for exciting by plasma one or both of said material gas and said control gas.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4 989 541
DATED : February 5, 1991
INVENTOR(S) : Nobuo MIKOSHIBA et al

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6, line 27; change "Claim 11" to ---Claim 1---.

Signed and Sealed this
Twenty-fourth Day of November, 1992

Attest:

DOUGLAS B. COMER

Attesting Officer

Acting Commissioner of Patents and Trademarks

[54] **HIGH PRESSURE ELECTRONIC
COMMON-RAIL FUEL INJECTION SYSTEM
FOR DIESEL ENGINES**

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Waterloo, Iowa 50702

[21] Appl. No.: 621,372

[22] Filed: Nov. 30, 1990

Related U.S. Application Data

[62] Division of Ser. No. 508,068, Apr. 11, 1990, Pat. No. 5,035,221, which is a division of Ser. No. 295,588, Jan. 11, 1989, abandoned.

[51] Int. Cl.³ F02M 37/00

[52] U.S. Cl. 123/456; 123/447;
137/883

[58] Field of Search 123/447, 452, 463, 494,
123/451, 456; 137/597, 883, 561 A, 884

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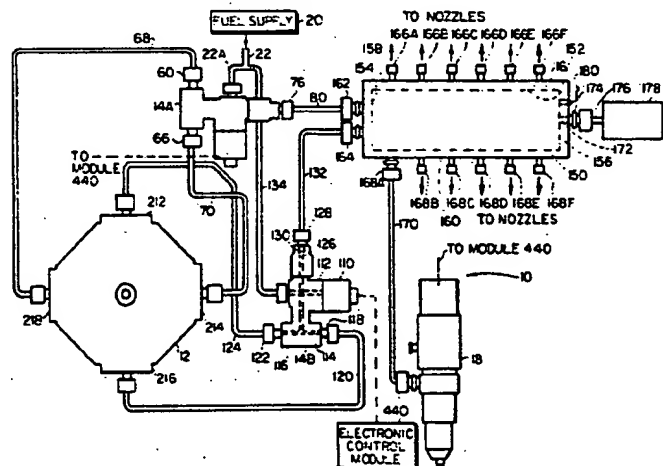
Primary Examiner—Carl Stuart Miller

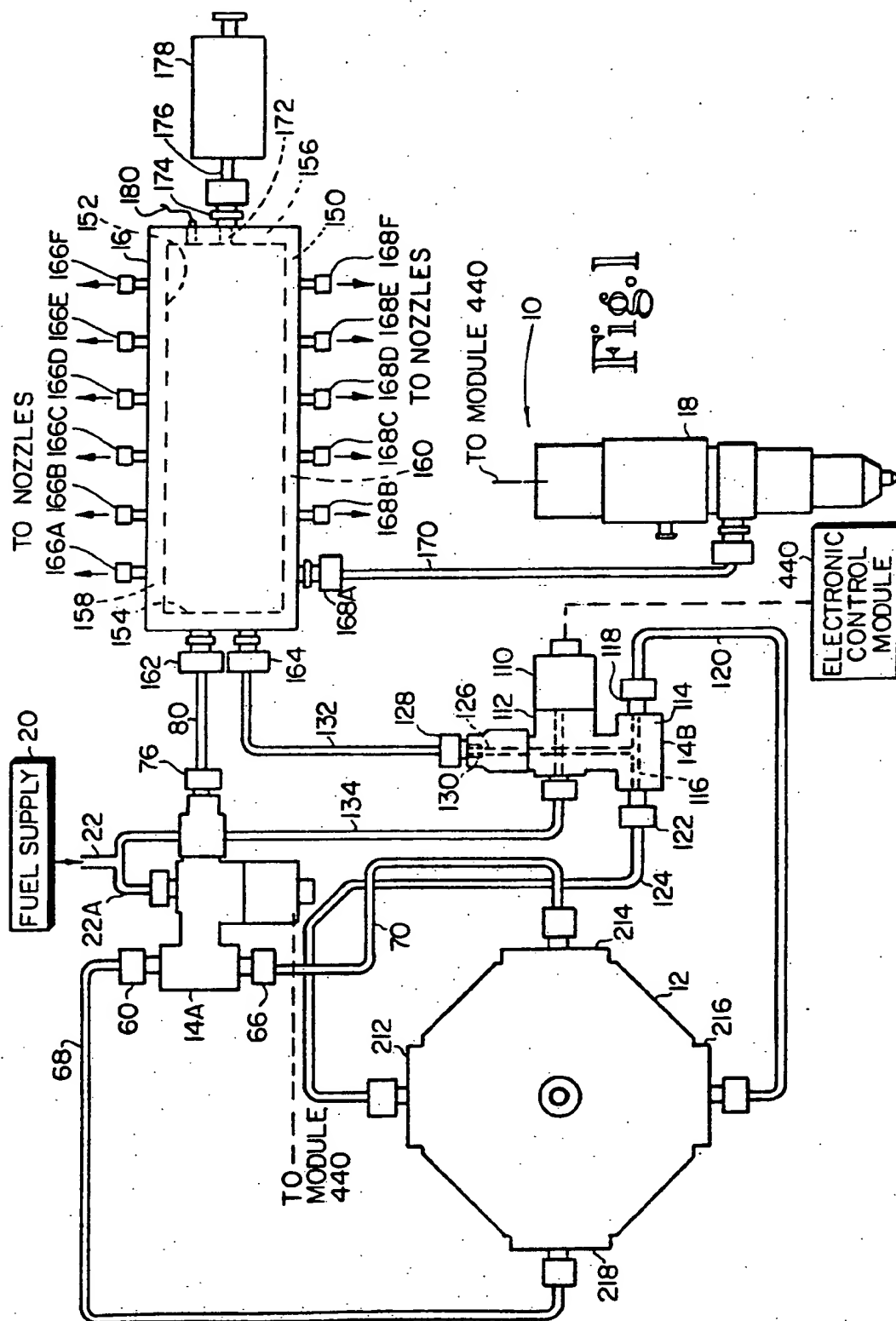
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[57] **ABSTRACT**

A fuel injection system having a novel electromagnetic-actuated fuel pump in which four pumping elements, equally-spaced around a camshaft are mounted such that a pair of opposed pumping elements alternate to deliver pressure to a high pressure common rail with a second pair of pumping elements. In one embodiment of the invention the pumping elements are mechanically actuated, in another they are electronically actuated. The high pressure common rail is adapted to reduce surges in the fuel pressure from the pump up to levels of 20,000 psi. The common rail has a relief valve for controlling the maximum pressure in the common rail chamber. The electromagnetic injection nozzle has a needle valve that is closed by pressure in a balancing chamber having a reduced pressure level less than that of the pressure required to open the valve. When the supply fuel flow is blocked, the valve is closed by a spring, assisted by the pressure in the balancing chamber which overbalances the needle valve when the nozzle pressure has dropped by the termination of the supply fuel flow.

1 Claim, 8 Drawing Sheets





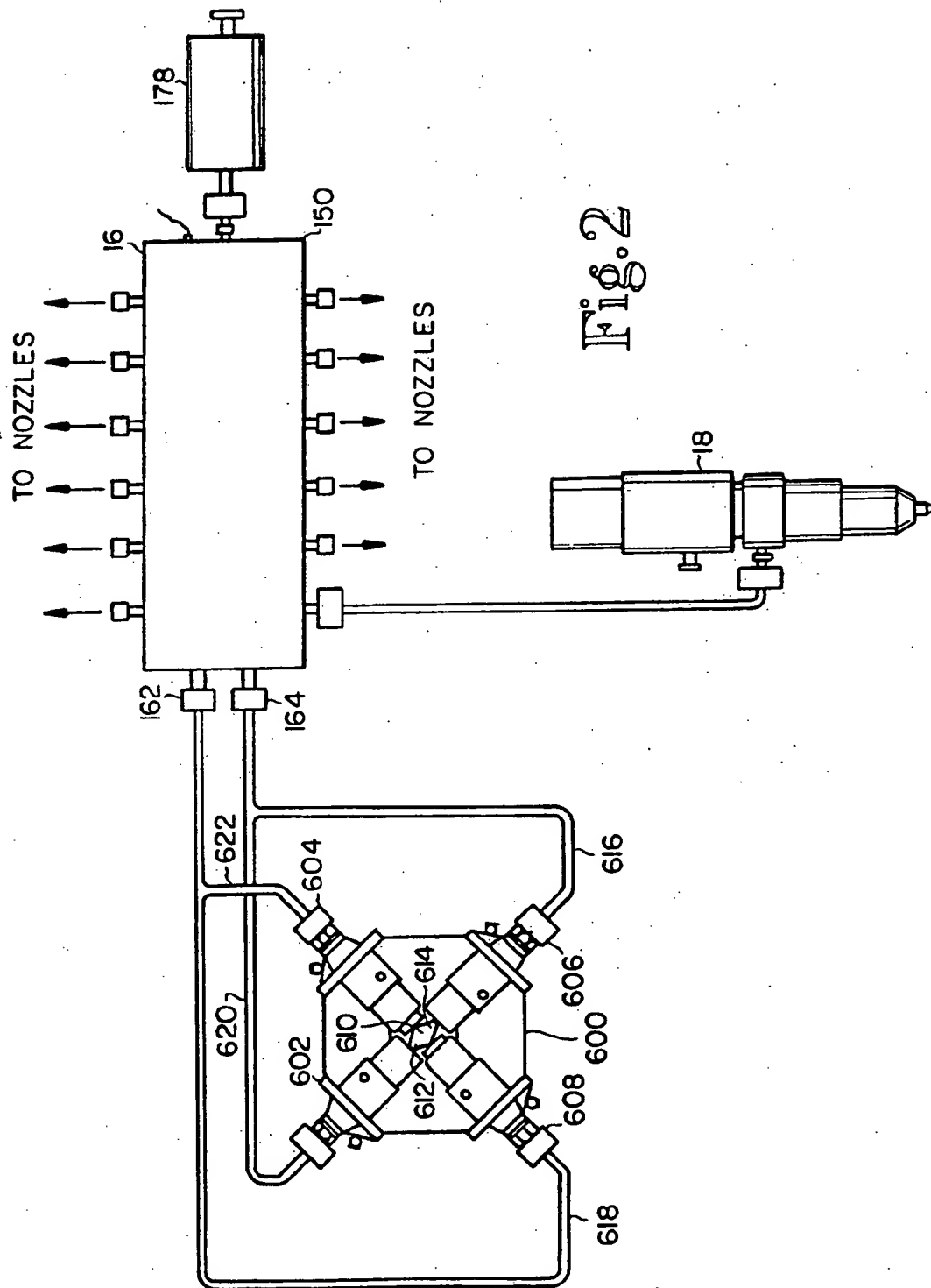


Fig. 2

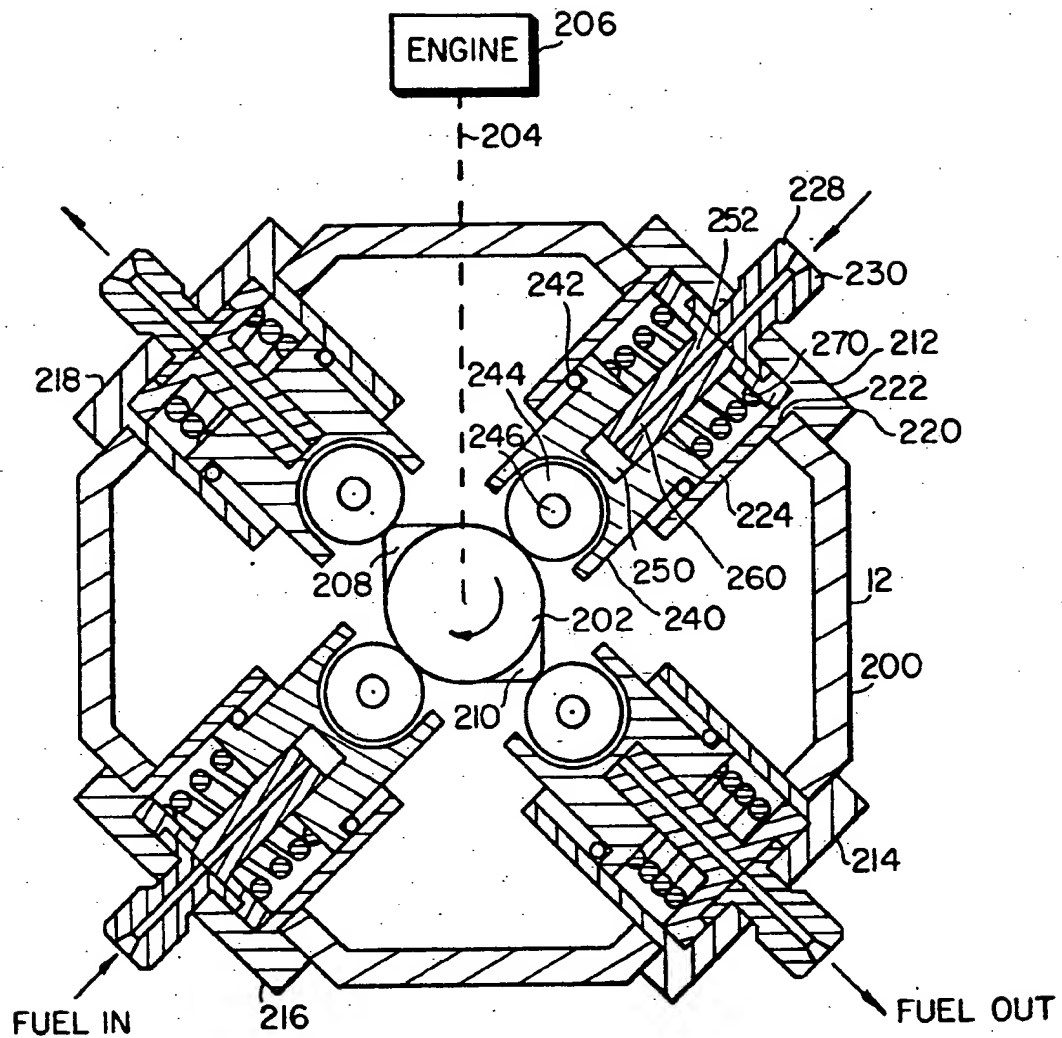


Fig. 3

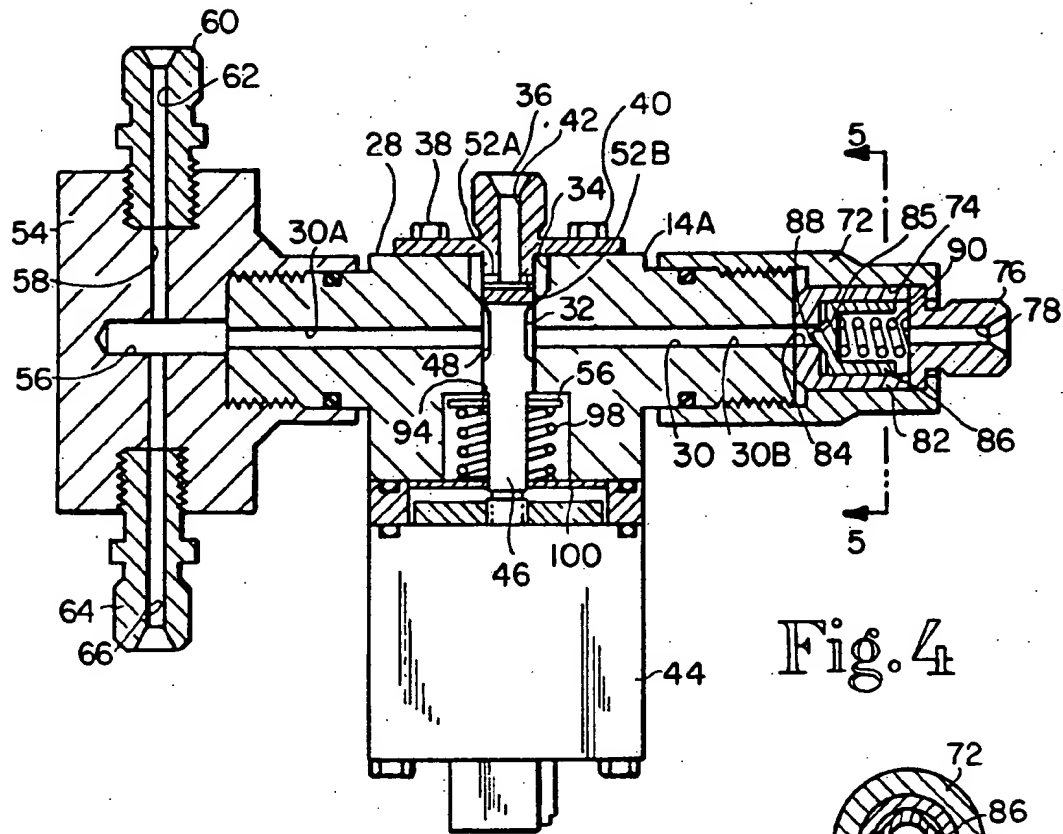


Fig. 4

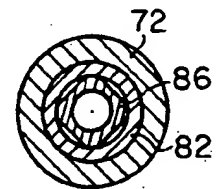


Fig. 5

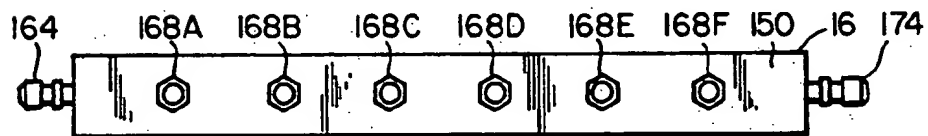


Fig. 6

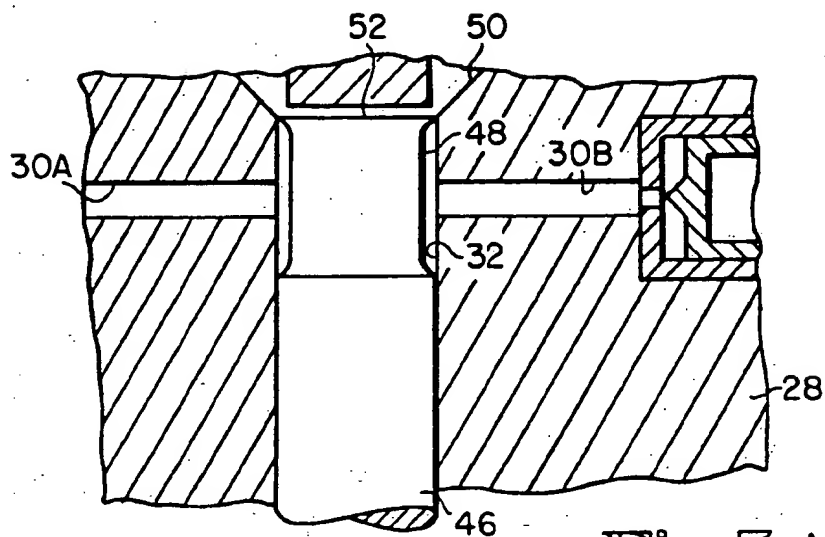


Fig. 5A

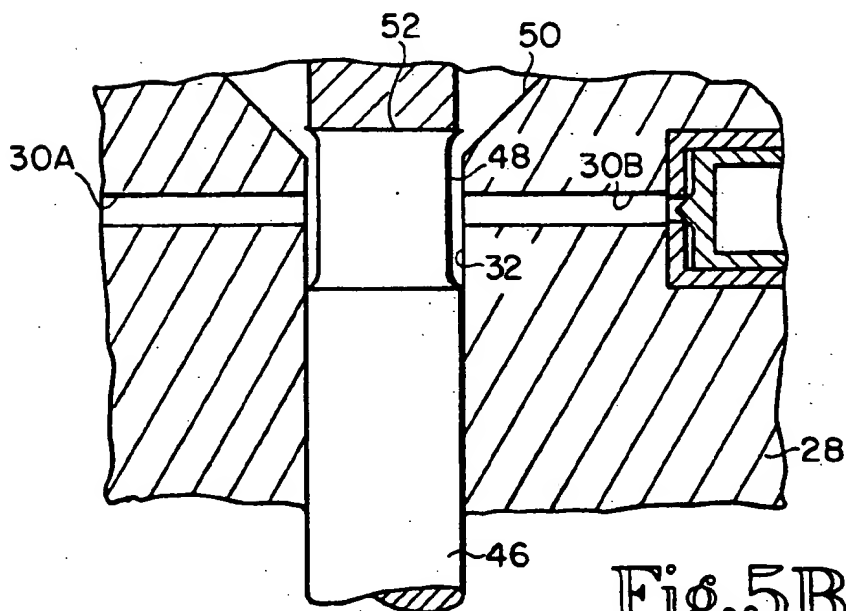


Fig. 5B

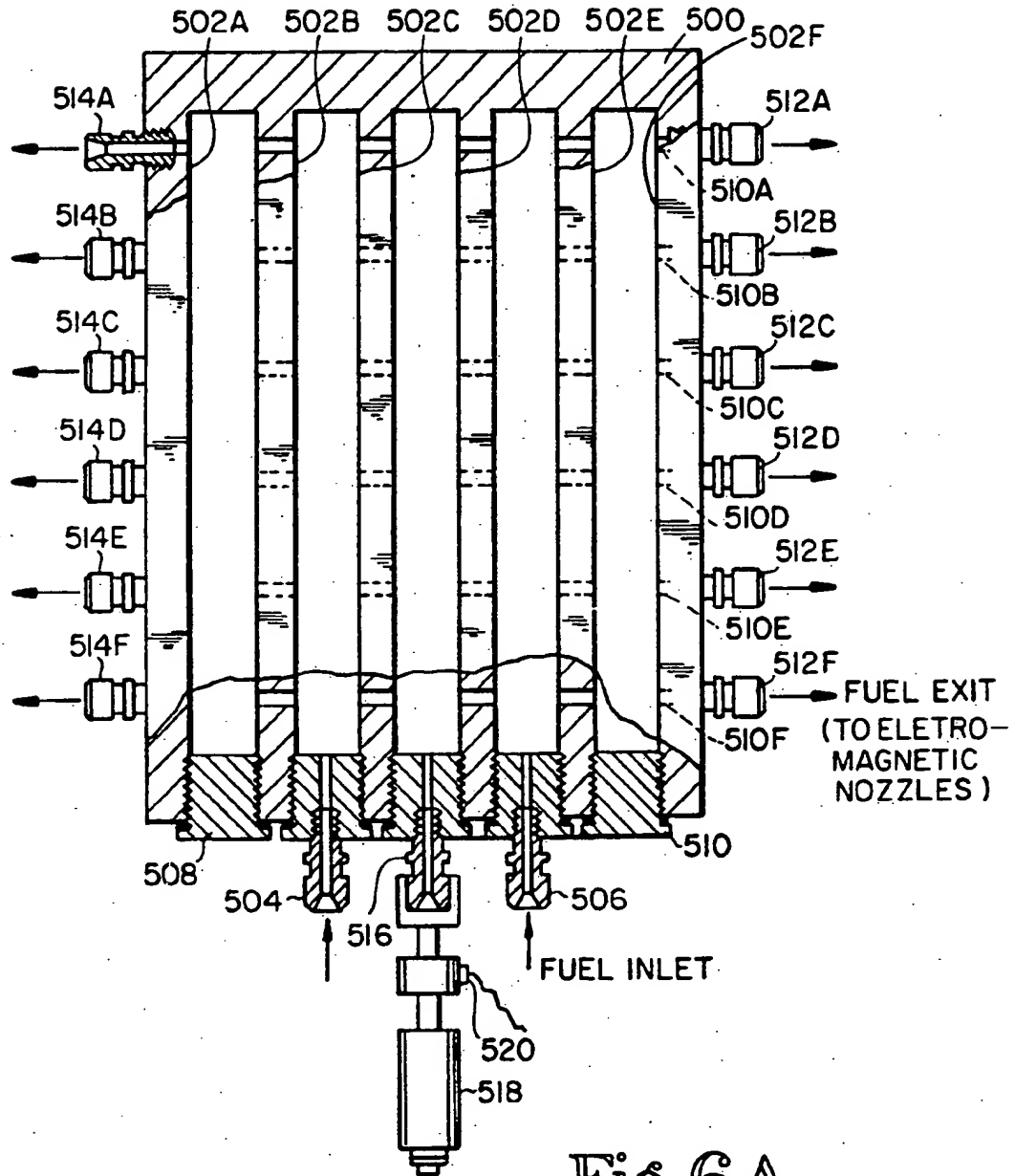
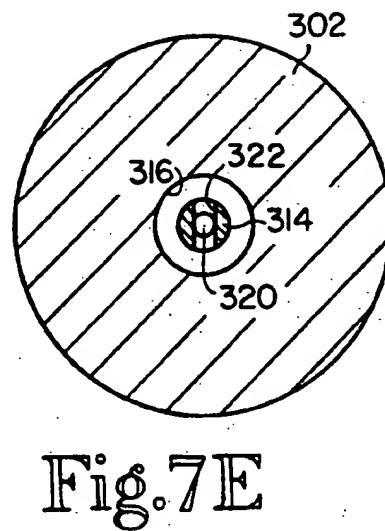
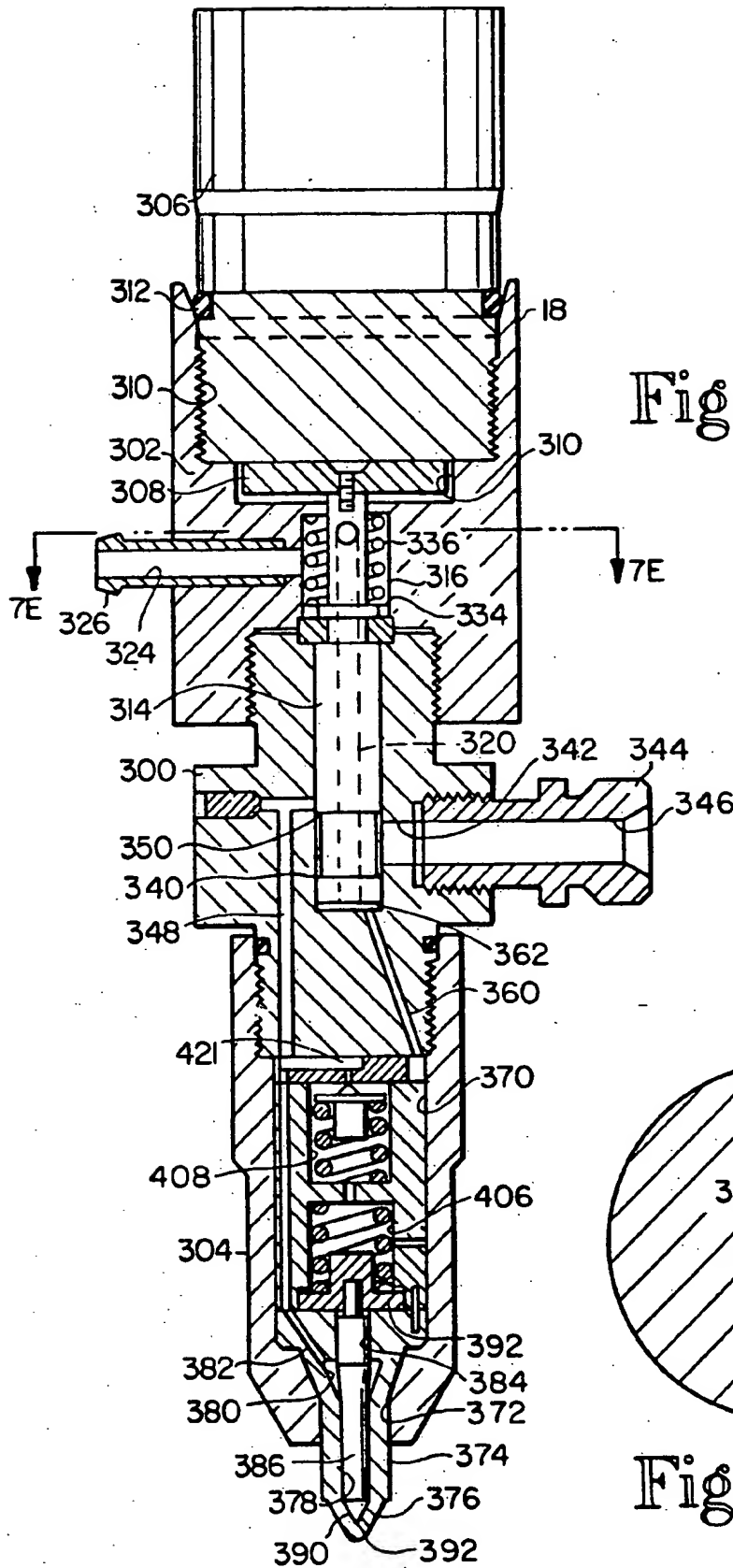
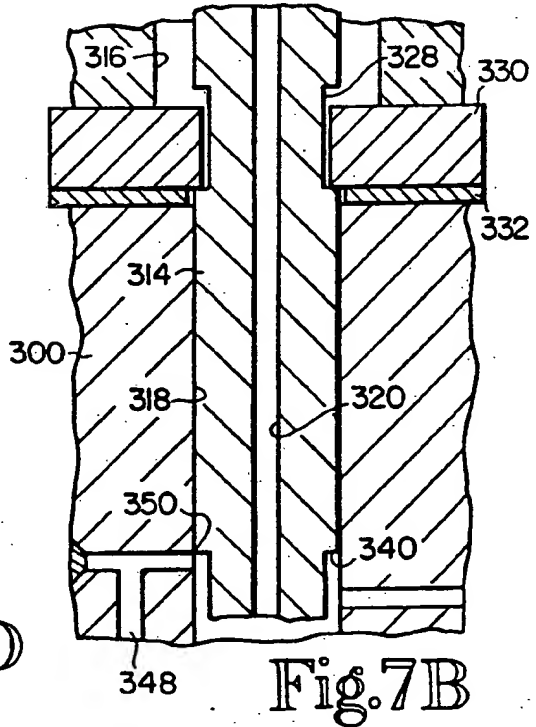
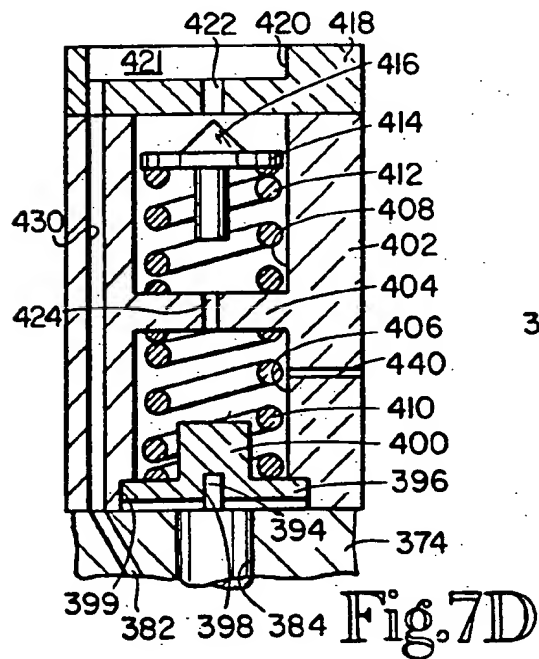
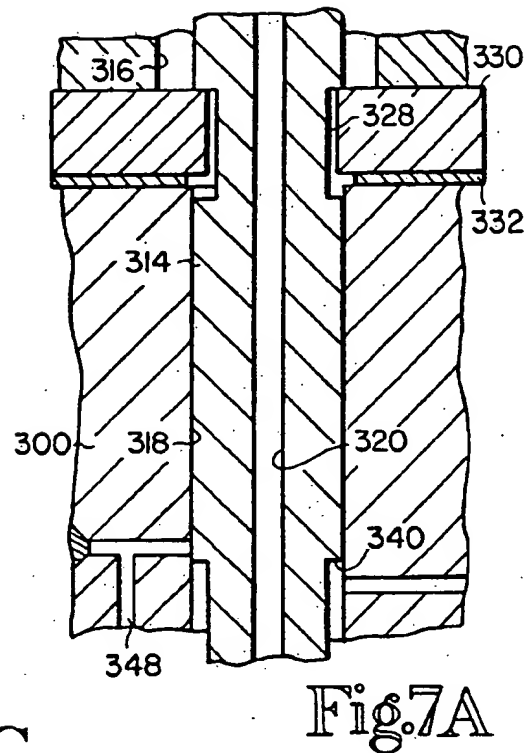
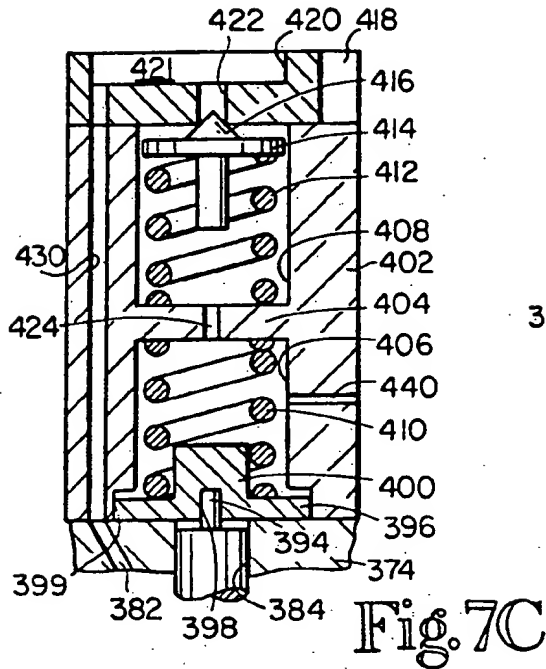


Fig. 6A





HIGH PRESSURE ELECTRONIC COMMON-RAIL FUEL INJECTION SYSTEM FOR DIESEL ENGINES

This application is a division of application Ser. No. 07/508,068, filed Apr. 11, 1990, now U.S. Pat. No. 5,035,221 which was a division of application Ser. No. 07/295,588, filed Jan. 11, 1989, now abandoned.

BACKGROUND OF THE INVENTION

This invention is related to a high-pressure, common rail, fuel injection system for injecting metered amounts of highly pressurized fuel into the cylinder of a diesel engine.

Conventional fuel injection systems employ a "jerk" type fuel system for pressurizing and injecting fuel into the cylinder of a diesel engine. A pumping element is actuated by an engine-driven cam to pressurize fuel to a sufficiently high pressure to unseat a pressure-actuated injection valve in the fuel injection nozzle.

In one form of such a fuel system having an electromagnetic unit injector, the plunger is actuated by an engine driven cam to pressurize the fuel inside the bushing chamber when a solenoid is energized and the solenoid valve is closed. The metering and timing is achieved by a signal from an electronic control module (ECM) having a controlled beginning and a controlled pulse.

In another form of such a fuel system, the fuel is pressurized by an electronic or mechanical pumping assembly into a common rail and distributed to electromagnetic nozzles which inject pressurized fuel into the engine cylinder. Both the electronic pump and the electromagnetic nozzles are controlled by the ECM signal.

One problem with using a common rail results from the high pressures experienced in diesel engines, in the neighborhood of 20,000 psi.

Another problem in conventional fuel injection systems lies in achieving a controlled duration and cut-off of the fuel injection pressure. Standard fuel injection systems commonly have an injection pressure versus time curve in which the pressure increases to a maximum and then decreases to form a somewhat skewed, triangularly-shaped curve. Such pressure versus time relationship initially delivers a relatively poor, atomized fuel penetration into the engine cylinder because of the low injection pressure. When the pressure curve reaches a certain level, the pressure provides good atomization and good penetration. As the pressure is reduced from its peak pressure, the decreasing pressure again provides poor atomization and penetration, and the engine discharges high emission particulate and smoke.

One of the objects of fuel injection designers is to reduce unburned fuel by providing a pressure vs. time curve having a squared configuration, with an initially high pressure increase to an optimum pressure providing good atomization, and a final sharp drop to reduce the duration of poor atomization and poor penetration.

Examples of some prior art fuel injection nozzles may be found in U.S. Pat. No. 4,527,737 which issued Jul. 9, 1985 to John I. Deckard; U.S. Pat. No. 4,550,875 which issued Nov. 5, 1985 to Richard F. Teerman, Russell H. Bosch, and Ricky C. Wirth; U.S. Pat. No. 4,603,671 which Aug. 5, 1986 to Turo Yoshinaga, et al.; U.S. Pat. No. 3,331,327 which issued to Vernon E. Roosa on Jul.

18, 1967; and U.S. Pat. No. 4,509,691 which issued Apr. 9, 1985 to Robert T. J. Skinner.

Literature pertaining to electromagnetic fuel injection pumps may be found in Paper No. 880421 of the SAE Technical Paper Series entitled "EMI-Series—ELECTROMAGNETIC FUEL INJECTION PUMPS" discussed at the Feb. 29–Mar. 4, 1988 International Congress & Exposition at Detroit, Mich. Other literature pertaining to the subject include: SAE Technical Paper Series No. 840273 discussed Feb. 27–Mar. 2, 1984 at the International Congress & Exposition, Detroit, Mich.; SAE Technical Paper Series 850453 entitled "An Electronic Fuel Injection System for Diesel Engines" by P. E. Glikin discussed at the International Congress & Exposition at Detroit, Mich. on Feb. 25, 1985; SAE Technical Papers Series 810258 by R. K. Cross, P. Lacra, C. G. O'Neill entitled ELECTRONIC FUEL INJECTION EQUIPMENT FOR CONTROLLED COMBUSTION IN DIESEL ENGINES, dated Feb. 23, 1981; SAE Technical Paper Series 861098 entitled EEC IV—FULL AUTHORITY DIESEL FUEL INJECTION CONTROL by William Weseloh presented Aug. 4, 1986; and, United Kingdom Patent Application No. GB-2118624A filed Mar. 3, 1983 by Henry Edwin Woodward.

SUMMARY OF THE INVENTION

The broad purpose of the present invention is to provide an improved high pressure common rail, fuel injection system. In the preferred embodiment, the system employs a novel electro-magnetic nozzle having a needle valve with an inner end attached to a piston that forms one wall of an accumulator or balancing chamber. Fuel is delivered to the nozzle by a solenoid-actuated valve. The high pressure fuel biases the needle valve to an open position. A portion of the high-pressure fuel is by-passed to the balancing chamber to urge the piston and the needle valve towards their closed position.

Initially, the pressure acting to open the needle valve is about 20,000 psi. The balancing chamber pressure by virtue of certain orifices, has an internal pressure of only about 7,000–8,000 psi.

When the fuel supply to the needle valve is terminated, the fuel pressure biasing the needle valve open begins to fall off. When the needle valve pressure is reduced to a level less than that in the accumulator chamber, the pressurized fuel in the balancing chamber, together with a spring, cooperate in quickly closing the needle valve. The result is a sharp cut-off pressure thereby reducing the duration of the tail end of the injection curve that customarily provides poor penetration and atomization.

The system employs a novel multi-element fuel pump. Four plunger-actuated pumping elements are mounted about a camshaft having a pair of lobes. When the camshaft turns 90 degrees, it moves a first pair of opposed plungers in a delivery motion, and the other two plungers in a suction motion. As the camshaft continues its rotation, the two pair of pumping elements alternate in delivering fuel toward a common rail.

In one embodiment, the pump is actuated by a solenoid-actuated valve in response to an electrical signal from an electronic control module.

In another embodiment, the pumping elements are mechanically actuated.

Two forms of common rails are disclosed. In both forms the common rail has a one-piece metal housing.

Fuel is delivered from the pump in one direction into the common rail, and discharged in a direction at right angles to the injection nozzles.

One form of common rail has a relatively flat metal body with a series of parallel, relatively large diameter bores. Some of the bores are capped off and the others connected to the pump. The body has a second series of smaller bores, at right angles to the first set of bores. Each end of the smaller bores is capped off with a discharge fitting. The pressure in the body is controlled by a relief valve. By adjusting the relief valve, the fuel pressure to the fuel injection nozzles is maintained constant during the duration of the injection process.

Still further objects and advantages of the invention will become readily apparent to those skilled in the art to which the invention pertains upon reference to the following detailed description.

DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a high-pressure, common-rail fuel injection system illustrating the preferred embodiment of the invention;

FIG. 2 illustrates a high-pressure, common-rail fuel injection system with a mechanical pump assembly;

FIG. 3 is a view of an electronically-actuated pump assembly illustrating the preferred fuel pump;

FIG. 4 is a view of a preferred solenoid valve assembly;

FIG. 5 is a sectional view as seen along lines 5—5 of FIG. 4;

FIG. 5A is an enlarged fragmentary view of the solenoid valve in a position for delivering fuel to the common rail;

FIG. 5B is an enlarged fragmentary view showing the solenoid valve disposed for bypassing the fuel;

FIG. 6 is a side view of the common rail of FIG. 1;

FIG. 6A is a sectional view of another preferred common rail;

FIG. 7 is a longitudinal sectional view of a preferred electro-magnetic nozzle;

FIGS. 7A and 7B are enlarged sectional views showing the inlet opening to the fuel injection nozzle body to the delivery passage;

FIGS. 7C and 7D are views of the internal pressure balancing chamber; and

FIG. 7E is an enlarged view as seen along lines 7E—7E of FIG. 7.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, a preferred fuel injection system 10 comprises an electronic pump means 12, solenoid valve means 14A and 14B, a common rail assembly 16 and an electro-magnetic nozzle means 18.

Fuel is delivered from a fuel supply 20 through conduit means 22 to solenoid valve means 14A and 14B. The two valve means 14A and 14B are identical in construction, their function differing according to their fluid connection with pump means 12.

Referring to FIG. 4, solenoid valve means 14A comprises a body 28 having a longitudinal passage 30 including halves 30A and 30B. A transverse passage 32 extends at right angles to passage 30 and intersects passage 30. One end of passage 32 is enlarged at 34. A fuel inlet fitting 36 is mounted in enlarged passage 34. A pair of fasteners 38 and 40 fasten fitting 36 to the body. Fitting 36 has a passage 42 for receiving fuel from conduit means 22A.

Referring to FIGS. 4, 5A and 5B, an electrically-operated solenoid 44 is mounted on the body and is operatively connected to control valve 46 which is slidably disposed in passage 32 for reciprocatory motion. Valve 46 has an annular groove 48 spaced from the outer end of the valve.

The bottom of the enlarged end of bore 34 is tapered at 50 to provide a seat for outer end 52 of valve 46.

Solenoid 44 is operative to move the control valve between a closed position (FIG. 5A) in which valve end 52 engages seat 50 to block fluid flow between passage 42 and an open position (FIG. 5B) in which the control valve abuts fitting 36 to open fluid flow between passage 32 and a pair of passages 52A and 52B in fitting 36 to passage 42. In both positions, there is a fluid connection between the two halves 30A and 30B of passage 30.

Referring to FIG. 4, nut 54 is mounted on one end of the body. Nut 54 has an internal passage 56 forming an extension of passage 30A. The nut has a second passage 58 at right angles to and intersecting passage 56. A fitting 60 is mounted on the nut and has an internal passage 62 forming an extension of one end of passage 58.

A second fitting 64 is mounted on the opposite end of the nut and has an internal passage 66 forming an extension of the opposite end of passage 58.

Referring to FIG. 1, conduit 68 forms a fluid connection between fitting 60 and pump means 12, and another conduit 70 forms a fluid connection between fitting 64 and pump means 12.

Returning to FIGS. 1, 4 and 5, a nut 72 is mounted on the opposite end of body 28. Nut 72 has an internal chamber 74. A threaded fitting 76 is mounted on nut 72. Fitting 76 has a passage 78 connected to a conduit 80. A cup-shaped member 82 is mounted in chamber 74. Member 82 has a cylindrical internal wall, and an opening 84 communicating with passage 30B which forms a valve seat 85 for a slidably mounted, hollow check valve 86. Check valve 86 has a conical end 88 which mates with valve seat 85 to close fluid flow from passage 30 into chamber 74. A spring bias member 90 is mounted in the check valve and biases it toward its closed position.

Referring to FIG. 5, check valve 86 has a square cross-section slidably mounted in the cylindrical internal wall of member 82 to permit fuel flow from passage 30 into chamber 74 when conical end 88 is spaced from the valve seat.

Still referring to FIG. 4, when solenoid means 44 is electrically energized, it retracts the control valve away from fitting 36 to open fluid flow between passage 32 and passage 42.

The control valve has an annular shoulder 94. A washer 96 is mounted on the shoulder. A return spring 98 is disposed between the washer and a retainer 100 to bias the control valve toward fitting 36 and the control valve's open position.

In operation, when the control valve is seated in its closed position, fluid flow is blocked between passage 32 and 22A. When check valve 86 is opened, fuel passes from the pumping means through passages 30A and 30B and out to conduit 80. When the control valve is raised to engage fitting 36 in the valve's open position, the fuel passes from passage 30A and out conduit 22A, when check valve 86 is closed.

Referring to FIG. 1, the second solenoid assembly 14B is identical in construction to solenoid 14A and includes a solenoid 110 mounted on a body 112. A nut

114 is mounted on one end of the body and has an internal passage 116. One end of passage 116 is connected by fitting 118 and conduit 120 to the pump assembly.

The opposite end of passage 116 is connected by fitting 122 and conduit 124 to the pump means in a manner which will be described. The body has internal passage means 126, one end of which is connected to passage 116 and the other end which terminates with fitting 128. A check valve 130 provides means for opening and closing fuel flow from the body to a conduit 132 which is connected to common rail 16. Fuel is received from fuel supply 20 through a conduit 134. Solenoid 110 moves control valve 111 to control fluid flow between passage 126 and conduit 134 in the manner that control valve 46 controls flow between passage 30 and conduit 22A.

Fuel is discharged from conduits 80 and 132 to common rail 16.

Referring to FIGS. 1 and 6, common rail 16 has a relatively flat metal body 150. Body 150 has an internal chamber 152 bounded by end walls 154 and 156, and side walls 158 and 160.

The side walls and the end walls are joined in a rectangular configuration.

End wall 154 has a pair of inlet fittings 162 and 164. Fitting 162 is connected to conduit 80 for receiving fuel from solenoid valve assembly 14A into the common rail chamber. Fitting 164 is adapted to receive fuel from the solenoid valve assembly 14B through conduit 132.

Side wall 158 has six fluid discharge fittings 166A through 166F.

The opposite side wall 160 has fluid discharge fittings 168A through 168F. Each of the fittings 166A through 166F, and 168A through 168F is connected by a conduit such as conduit 170 to an electromagnetic nozzle typified by nozzle means 18.

End wall 156 has an outlet opening 172. A fitting 174 is mounted in the outlet opening and connected by a conduit 176 to an adjustable relief valve 178. Adjustable relief valve is adapted to relieve the pressure in chamber 152 when it exceeds a predetermined level.

A pressure transducer 180 is also mounted in end wall 156 and connected to a remote indicator (not shown) for monitoring the pressure in chamber 152.

Referring to FIGS. 1 and 3, fuel pump means 12 comprises a housing 200. A camshaft 202 is mounted in the housing and connected by mechanical connection 204 to the engine 206 being supplied by the fuel delivery means.

The camshaft has two lobes 208 and 210 mounted 180 degrees apart.

Four identically constructed pumping means 212, 214, 216 and 218 are mounted on the housing, spaced 90 degrees with respect to one another about the axis of rotation of the camshaft. Pumping means 212 is typical of the four and includes a mounting flange 220 disposed in an opening 222 in the pump housing. The flange carries a cylindrical skirt 224 and supports a fitting 228 having an internal passage 230.

A tappet bushing 240 is mounted in skirt 224. A retaining ring 242 is carried by the bushing and slidably mounted on the inner surface of skirt 224.

A tappet 244 is rotatably mounted on a pin 246 carried by the bushing. The tappet is rotatably engaged with the camshaft such that the bushing is movable within the skirt depending upon the position of the camshaft.

The bushing has an internal bore 250. A plunger 252 is slidably mounted within the bore to form a pumping chamber 256 which expands and contracts depending upon the position of the tappet on the camshaft. The plunger has an internal passage 260 for passing fuel toward or away from pumping chamber 256. The arrangement is such that as the tappet rides up on either camshaft lobe 208 or lobe 210, the tappet moves the bushing toward the plunger to reduce the size of pumping chamber 256, thereby delivering fuel under pressure through passage 230. As the camshaft is rotated so the tappet is riding on the back side of the camshaft lobe, a spring bias member 270 having one end engaged with the plunger and its other end engaged with the bushing, urges the bushing toward the camshaft to enlarge chamber 256. As pumping chamber 256 is enlarged, the chamber creates a low pressure area drawing fuel into the chamber through the passage in the plunger.

Thus it can be seen that as the camshaft is rotated, it simultaneously pumps fuel out of the pumping chambers of pumping means 214 and 218, while drawing fuel into the pumping chambers of pumping means 212 and 216. As the camshaft continues its rotation, the fuel is drawn into the pumping chamber of pumping means 214 and 218, and pumped out of the pumping chambers of pumping means 212 and 216. This provides a pumping action having a balanced motion of the pumping components.

Referring to FIG. 1, pumping means 212 and 216 are connected by conduits 124 and 120, respectively, to solenoid assembly 14B.

Similarly, pumping means 214 and 216 are connected by conduits 70 and 68, respectively, to solenoid assembly 14A. The pumping means either pump fuel toward the common rail or recirculate it to the fuel supply conduits depending upon whether the check valves in the solenoid valves are open or closed. The check valves are open or closed depending upon the pressure in common rail chamber 16 which in turn is a function of the relief valve adjustment and the fuel flow through the electromagnetic nozzles.

Referring to FIGS. 7, 7A, 7B, 7C and 7D, a typical electromagnetic nozzle 18 comprises a body 300 having a nut 302 threadably mounted at its upper end; and a retaining cap 304 mounted at its lower end. An electrically-actuated solenoid 306 is mounted on the nut. The solenoid has an armature 308 disposed in a chamber 310 which defines the travel of the armature. Solenoid 306 is seated in a cavity 310 by means of "O" ring 312.

The armature of the solenoid is connected to an elongated valve 314 which extends through a chamber 316 in the nut. Valve 314 is slidably mounted in bore 318 in the body. The valve has an internal longitudinal passage 320. A cross-passage 322 has its ends communicating with chamber 316 (FIG. 7E) which in turn communicates with passage 324 in fitting 326.

Referring to FIGS. 7A and 7B, valve 314 has an annular groove 328. An annular retaining plate 330 is mounted in the groove and has a thickness slightly less than the width of the groove. A shim 332 is mounted adjacent the retaining plate.

The difference between the thickness of the retaining plate and the width of the groove defines the length of travel of valve 314.

FIG. 7A illustrates the valve in its lower position in abutment with retaining plate 330, while FIG. 7B shows the valve in its upper position in abutment with the lower edge of retaining plate 330.

Valve 314 has an annular shoulder 334 disposed in chamber 316. A return spring 336 is mounted in the chamber with one end in abutment with nut 302, and the other end in abutment with shoulder 334 to bias valve 314 toward the retaining cap.

The valve has an annular passage 340 adjacent its lower end. The body has an internal passage 342 in communication with passage 340. A threaded fitting 344 is mounted on the body with an inlet passage 346 in communication with passage 342. Passage 342 is connected through conduit 170 for receiving fuel from the common rail chamber. The body also has a delivery passage 348 with an inlet opening 350 terminating at bore 318. The location of opening 350 is such that when valve 314 is in its lower-most position, the valve blocks fluid flow through opening 350. When the valve is in its upper position, it opens a fluid connection between annular passage 340 and inlet opening 350.

Referring to FIG. 7, the body also has a passage 360 extending from the bottom of bore 318 to the bottom of the body. A small chamber 362 is defined between the lower, extreme end of the valve and the bottom of bore 318 to provide fluid communication between passage 320 and passage 360.

Retaining cap 304 has a large internal chamber 370. Chamber 370 has a bottom opening 372. An elongated spray tip 374 is disposed in the chamber with its lower end extending through opening 372. The outer end of the spray tip has opening means 376 for passing fuel to the engine cylinder (not shown). The spray tip has an elongated, slightly tapered passage 378. The lower end of passage 378 passes fuel to opening means 376. The upper end of passage 378 is enlarged at 380 and fluidly connected to a passage 382 in the spray tip. Enlarged section 380 is tapered and terminates with a cylindrical bore 384 which extends through the upper end of the spray tip.

A needle valve 386 is mounted in passage 378. The lower end of the needle valve is tapered at 390 to seat against a tapered seat 392 in the spray tip for opening or closing fuel flow through passage means 376. The upper end of the needle valve has a narrowed end 394.

A piston 396 has a bore 398 receiving narrowed end 394 of the needle valve. Piston 396 is movable in a recess 399 to define the travel of the needle valve between its open and closed positions. The piston has a raised midsection 400.

Referring to FIGS. 7C and 7D, spring cage 402 is mounted in chamber 370. The cage has a wall 404 separating a lower balancing chamber 406, and an upper balancing chamber 408. A coil spring 410 in the lower chamber has its upper end engaging wall 404, and its lower end engaging piston 396 to urge it and the needle valve toward its closed position. A coil spring 412 in the upper chamber has its lower end engaged with wall 404. A valve 414 is mounted in the upper chamber and engages the upper end of spring 412. Valve 414 has a tapered valve section 416.

A cap 418 is mounted between the upper end of the spring cage and the lower end of body 300. Cap 418 has a cutout portion 420 forming a chamber 421 between the cap and the body 300, and an orifice 422 communicating between chamber 421 and upper balancing chamber 408. An orifice 424 in wall 404 provides communication between upper balancing chamber 408 and lower balancing chamber 406.

The cage also has a passage 430 having its upper end communicating with chamber 421, and a lower end connected to passage 382 in spray tip 374.

The cage also has a lateral orifice 440 which extends from lower chamber 406, upwardly along the wall of chamber 370 to provide communication with the lower end of passage 360.

OPERATION

Referring to FIG. 1, during engine operation, the fuel from supply 20, such as a fuel tank, is delivered at a predetermined pressure by a supply pump (not shown) to electronic pump assembly 12 through solenoid valve means 14A and 14B. The opposed pumping elements of the pump assembly draw fuel into the pumping chambers as the camshaft is turned, and then deliver the fuel to the solenoid valve assemblies.

The fuel from the pumping elements passes through the solenoid valve assemblies and is recycled to the fuel supply depending upon the position of the check valves. For example, when solenoid valve assembly 14A is energized with a certain pulse width by a signal from electronic control module 440, the solenoid armature closes the solenoid valve, the fuel pressure in passage 30 opens check valve 82 to pass fuel through fitting 76 toward the common rail.

The fuel coming from the solenoid valve assemblies enters into the common rail housing through either fitting 162 or 164, depending upon which solenoid valve assembly is in the pumping mode. The fuel is accumulated in the common rail at a predetermined pressure adjusted according to relief valve 178.

The high-pressure fuel in the common rail absorbs the pumping strokes and the reflecting pressure waves, delivering a constant, pressurized fuel to each of the electro-magnetic valves through their corresponding outlet fitting. The pressure in the common rail is monitored by a pressure transducer connected to fitting 180 which sends a signal back to electronic control module 440 which in turn opens the solenoid control valves.

FIG. 1 illustrates a practical common rail configuration using cross-drilled holes.

FIG. 6A illustrates another common rail comprising a one-piece metal housing 500 having five drilled holes 502A, 502B, 502C, 502D, and 502E. Inlet fittings 504 and 506 are mounted at the open end of holes 502B and 502D. Each inlet fitting has an internal passage for receiving fuel. Plugs 508 and 510 are inserted in the inlet of bores 502A and 502E. The housing is cross-drilled to form passages 510A to 510F. These are completely drilled through the block and six nipples 512A to 512F are mounted at one end of the passages 510A to 510F. Six nipples 514A-514F are mounted at the opposite ends of drilled holes 510A-510F. Each of the outlet nipples is adapted to discharge fuel from the six internal chambers formed by bores 502A to 502E. A nipple 516 is mounted in the inlet of drilled hole 502C and supports relief valve 518 and a pressure transducer 520. Relief valve 518 is similar to relief valve 178 in that it regulates the maximum pressure being maintained in the common rail.

The fuel pressure from the common rail is delivered to each of the electromagnetic nozzles, entering the nozzle body through fitting 344. The fuel flow stops at valve 314 which is normally closed. When solenoid 306 is energized with a pulse width at the beginning of an injection event from module 440, the armature and valve 314 are lifted, opening fuel flow through inlet 350,

passages 348, 430 and 382. The solenoid valve is pressure-balanced by the upper and lower sides of passage 340. The pressurized fuel continues to the spray tip. The fuel pressure acting against the tapered section 386 of the needle valve lifts the needle valve and permits the pressurized fuel to spray into the combustion chamber through spray opening means 376.

At the same time, the pressurized fuel from chamber 421 opens valve 416, continues downwardly into chamber 408 through orifice 424 into chamber 406. The pressure in balance chamber 406 rises at a lesser rate than is acting to raise the needle valve. The pressure in chamber 406 depends upon the net flow passing through orifices 424 and 440. Spring 412 assists in closing the needle valve.

The pumping process ends when the solenoid valves of valve means 14A and 14B are de-energized, and the return springs open the solenoid control valves such that fuel from the pump means returns to the supply conduits rather than to the common rail. The signal to de-energize is caused by the transducer 180 indicating that the common rail channel is at the predetermined level.

When solenoid 316 on the injection nozzle is de-energized, control valve 314 closes. The pressure in chamber 406 is controlled such that it is less than that being delivered to the spray tip. When the needle valve begins to close because the supply pressure has been cut-off by control valve 314, the pressure at the nozzle then drops until it is less than that urging piston 396 to close at which time the pressure in balance chamber 406, to-

gether with assistance from spring 410 abruptly closes the needle valve, ending the injection process.

FIG. 2 illustrates a mechanical pump assembly 600 using four standard plunger-operated, one-cylinder pumps 602, 604, 606 and 608, each having a fuel metering and timing adjusted by the plunger's helix. The plungers are energized in pairs by a crankshaft 610 having a pair of opposed cam lobes 612 and 614.

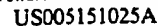
The pumps alternate in pairs in delivering fuel to common rail 16 through conduits 616, 618, 620 and 622 in a manner similar to the embodiment of FIG. 1.

Having described my invention, I claim:

1. A high pressure common rail for use in a diesel fuel injection system comprising:

- 15 a body formed of a unitary structure having a plurality of parallel first elongated bores formed from one end thereof and a plurality of second bores intersecting the first bores at right angles to the longitudinal axis thereof to form a plurality of communicating internal chambers, inlet fittings being mounted in the first bores adapted to receive fuel under pressure into the first bores and outlet fittings being mounted in the second bores for discharging fuel from the second bores, under the influence of the inlet fuel pressure; and
- 20 relief valve means connected to the internal chambers to prevent the fluid pressure in the internal chambers from exceeding a predetermined level whereby the fuel pressure being discharged from the internal chambers is generally at said predetermined pressure.

* * * * *



[11] Patent Number: 5,151,025

[45] **Date of Patent:** Sep. 29, 1992

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Primary Examiner—Tim Heitbrink
Attorney, Agent, or Firm—Peter K. Kontler

[57] **ABSTRACT**

§ 102(e) Date: **Aug. 16, 1991**

PCT Pub. Date: May 16, 1991

Oct. 26, 1989 [DE] Fed. Rep. of Germany 3935667

[58] **Field of Search** 210/411, 430; 425/197,
425/199, 225, 549, 565, 568

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35 Claims, 4 Drawing Sheets

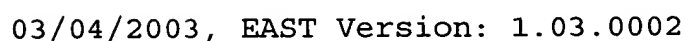


Fig. 1

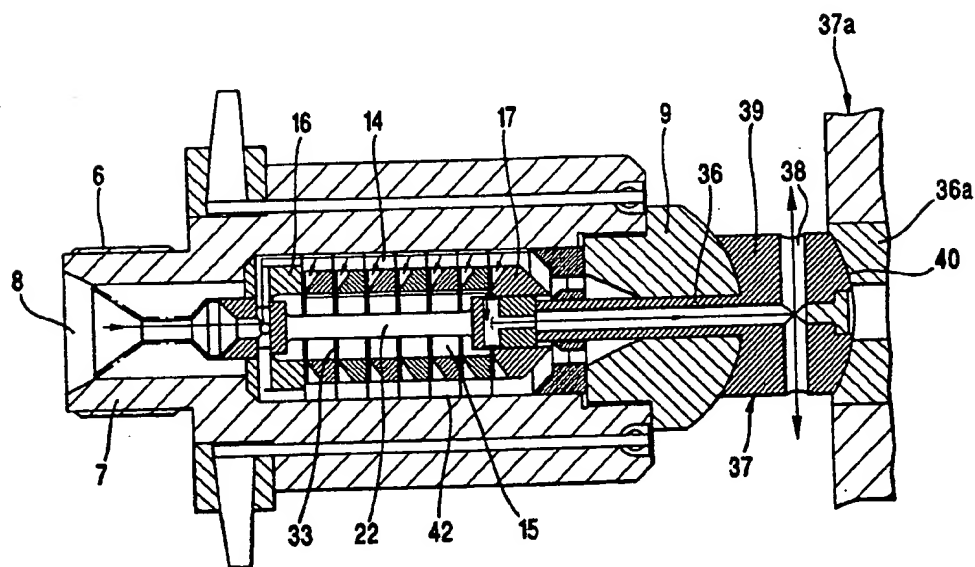
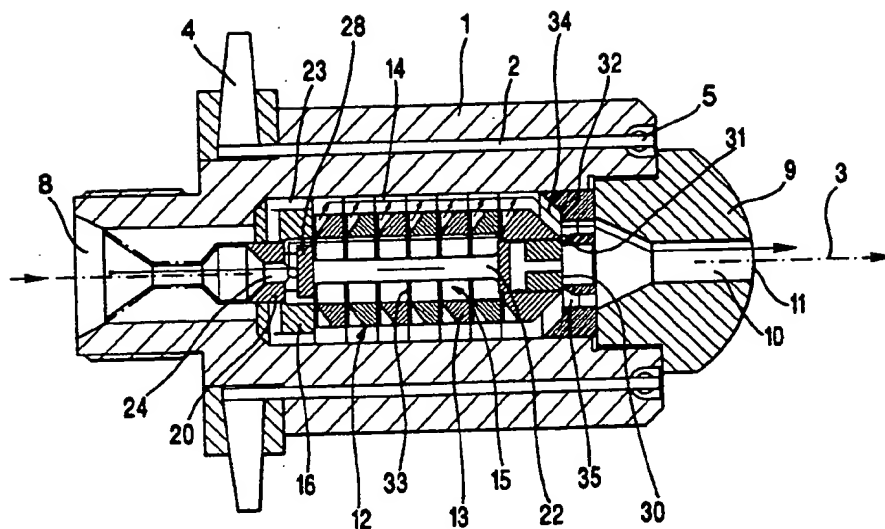


Fig. 2

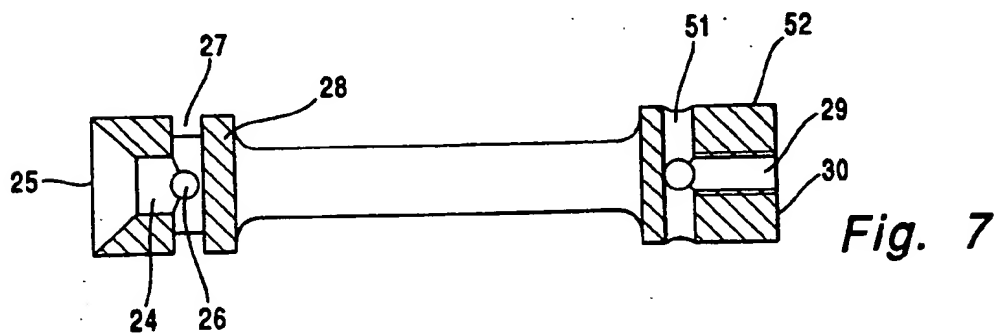
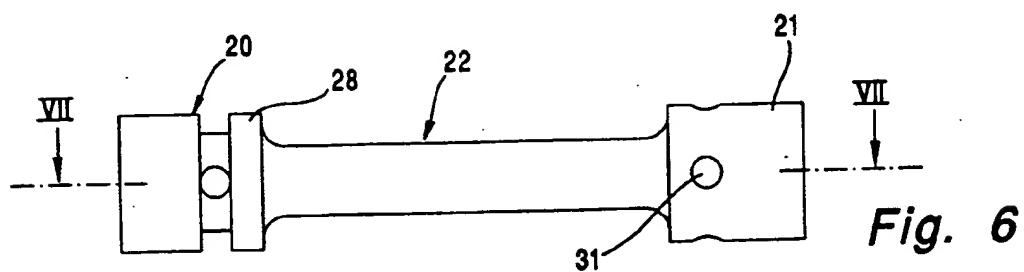
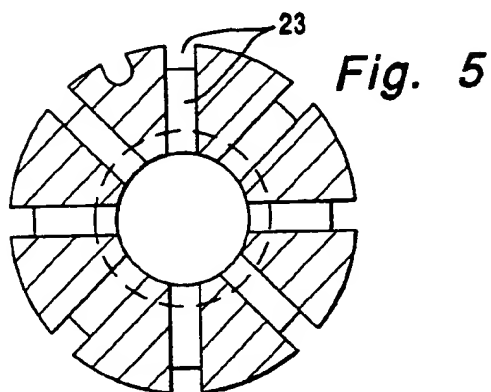
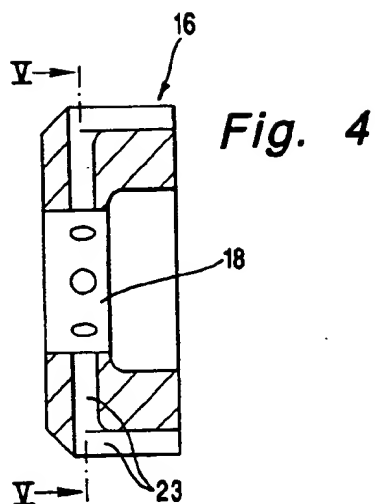
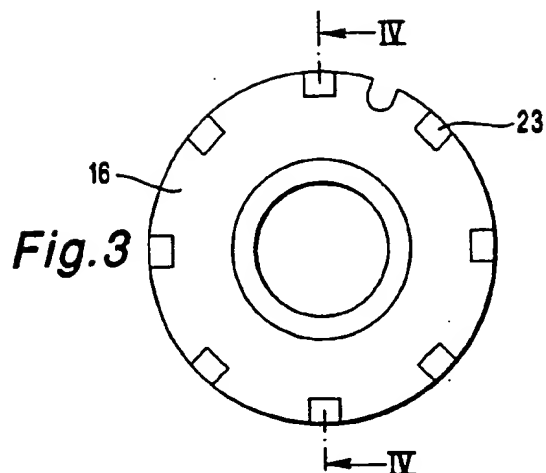


Fig. 8

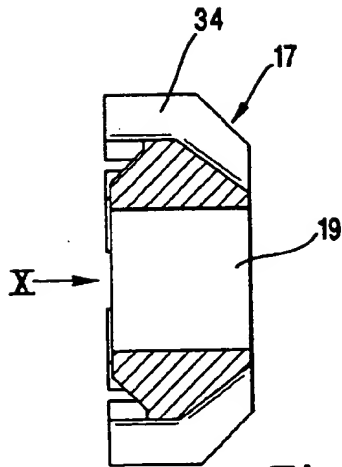
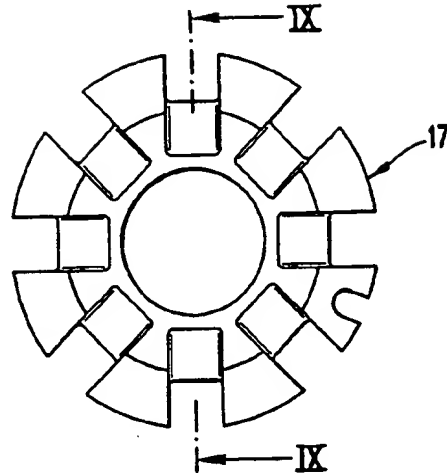


Fig. 9

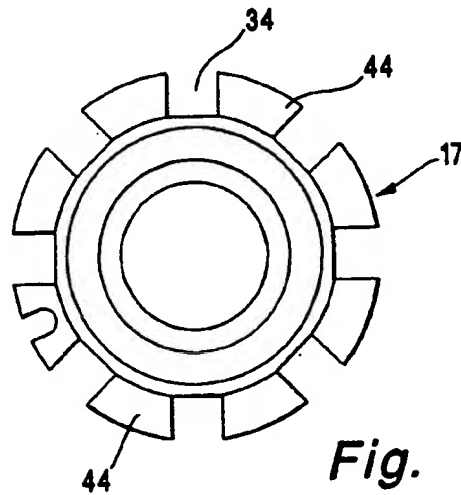


Fig. 10

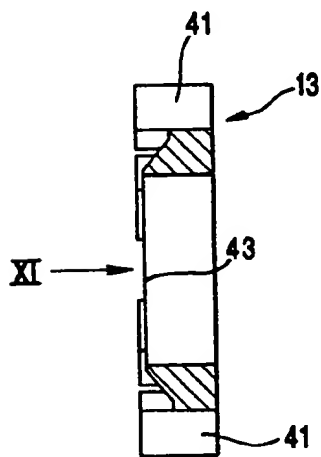


Fig. 12

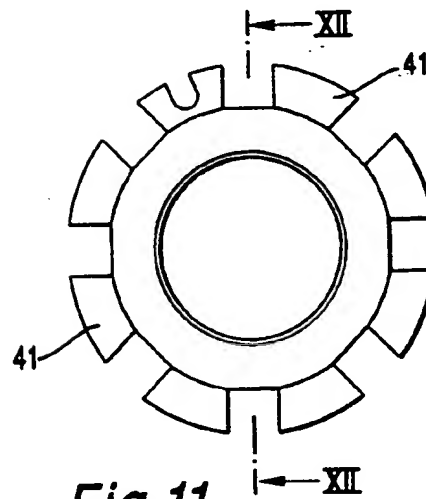


Fig. 11

Fig.14

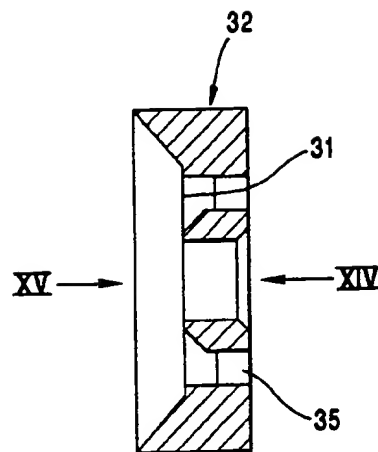
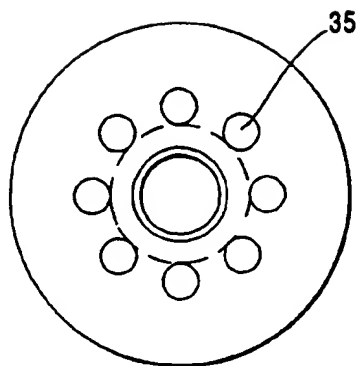


Fig. 13

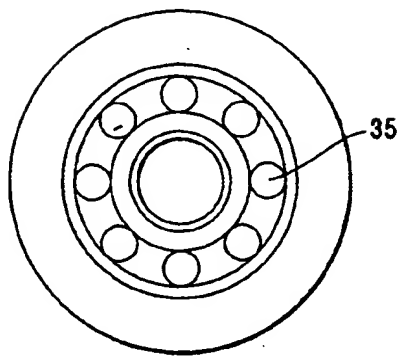


Fig. 15

ELECTRICALLY HEATABLE NOZZLE FOR AN INJECTION MOLDING MACHINE, A HOT RUNNER SYSTEM OR THE LIKE

BACKGROUND OF THE INVENTION

The invention relates to an electrically heatable nozzle for an injection molding machine, a hot runner system or the like. The nozzle has an inlet opening, an internal chamber and an outlet opening through which molten material, preferably molten plastic, flows.

Nozzles of this type are known (German Offenlegungsschrift 33 35 277) and have a nozzle passage via which the molten material is conveyed to a group of molds. During travel from the production location for the molten material to the group of molds, foreign particles which affect the quality of the molten material and the end product can enter the molten material.

SUMMARY OF THE INVENTION

It is an object of the invention to so design an electrically heatable nozzle of the type indicated at the outset that contaminants resulting from foreign particles can be removed from the molten material, and that these contaminants can be evacuated from the nozzle during a cleansing phase.

According to the invention, this object is achieved in that an annular strainer is placed in the internal chamber of the nozzle and divides the internal chamber into an annular outer compartment and an inner compartment. A switching device is provided and is movable between and arrestable in two terminal positions of which one is designed for the injection procedure and the other for the cleansing procedure. In the one terminal position, the molten material is admitted into the outer compartment and flows through the annular strainer from outside to inside. In the other terminal position, the molten material is introduced into the inner compartment and flows through the annular strainer from inside to outside.

In an advantageous embodiment of the invention, the switching device has a bolt-like control slide whose longitudinal axis coincides with the longitudinal axis of the nozzle and the longitudinal axis of the outlet opening. The servopiston is moved into the terminal position for the cleansing procedure by a switching tube which is introduced into the outlet opening from outside so that the contaminants retained by the annular strainer can be withdrawn via the switching tube.

In this manner, reversal of the control slide becomes very simple. The piston-like end portion of the control slide facing the inlet opening is subjected to the pressure of the admitted molten material which exerts a force on the control slide causing the control slide to move into, or to be held in, the terminal position corresponding to the injection procedure. The control slide is moved into the other terminal position corresponding to the cleansing procedure by the switching tube introduced through the outlet opening. The control slide is held in this terminal position by the switching tube against the pressure of the molten material, and the molten material is conducted through the nozzle in such a manner that it conveys the contaminants accumulated at one side of the strainer to the outside via the switching tube. After removal of the contaminants, the switching tube is withdrawn from the nozzle. The molten material subsequently pushes the control slide into the other terminal

position so that the nozzle can again operate in the injection mode.

BRIEF DESCRIPTION OF THE DRAWINGS

5 An electrically heatable nozzle in accordance with the invention is illustrated in the drawings and is described below.

There is shown:

FIG. 1 a longitudinal section of the nozzle during the injection procedure,

FIG. 2 the nozzle of FIG. 1 together with a switching tube and a mold during the cleansing procedure,

FIG. 3 an elevational view of a guiding disc for the bolt-like control slide,

FIG. 4 a section along the section line IV—IV of FIG. 3,

FIG. 5 a section along the line V—V of FIG. 4,

FIG. 6 the bolt-like control slide,

FIG. 7 a section along the line VII—VII of FIG. 6,

FIG. 8 another guiding disc,

FIG. 9 a section along the line IX—IX of FIG. 8,

FIG. 10 a view in the direction of the arrow X of FIG. 9,

FIG. 11 an elevational view of a strainer disc,

FIG. 12 a section along the line XII—XII of FIG. 11,

FIG. 13 a vertical section of an end disc disposed next to the nozzle tip,

FIG. 14 a view in the direction of the arrow XIV of FIG. 13 and

FIG. 15 a view in the direction of the arrow XV of FIG. 13.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

35 The nozzle of FIGS. 1 and 2 has a cylindrical housing 1 made of a material with low effective electrical resistance. In the housing, electrically heatable wires 2 having a high effective electrical resistance are distributed about the periphery. The wires 2 are surrounded by an insulating layer and extend parallel to the longitudinal axis 3 of the nozzle. One end of each heating wire is in engagement with a current source 4 while the other end 5 is connected to the housing.

The housing has a coupling portion 7 which is provided with an external thread 6 and allows the housing to be affixed to the front end of an injection molding machine. However, the nozzle can also be employed in a hot runner system or similar devices. The coupling portion 7 with the external thread 6 has an inlet opening 8 for the molten material. The front end of the nozzle is equipped with a nozzle tip 9 which is screwed into a threaded opening of the housing 1. The nozzle tip has a nozzle passage 10 and an outlet opening 11 for the molten material.

55 An annular strainer 12 composed of several strainer discs 13 which are arranged side-by-side and can be aligned relative to one another divides the internal chamber of the nozzle into an annular outer compartment 14 and an inner compartment 15. Referring also to FIGS. 10 and 11, each strainer disc 13 has ribs 41 which define flow channels, and an end face 43 which is separated from an adjacent disc by an annular gap 33.

The strainer discs 13 making up the annular strainer 12 are disposed between a rear guiding disc 16 and a front guiding disc 17. These guiding discs have central bores 18 and 19 (FIGS. 4 and 9) which slidably support piston-like end portions 20, 21 (FIG. 6) of a bolt-like control slide 22.

The guiding disc 16 located next to the inlet end of the nozzle has angular channels 23 (FIGS. 1 and 3-5) which extend from the central bore 18. The channels 23 initially run radially, then run axially, and open into the outer compartment 14.

The end portion 20 of the control slide 22 has a central blind bore 24 (FIGS. 1 and 7) which extends from the outer end face 25. Radial bores 26 (FIG. 7) run outwards from the end of the blind bore and open into an annular groove 27. This annular groove 27 is flanked on one side by a disc 28 of the end portion 20.

The end portion 21 is provided with a central blind bore 29 (FIG. 7) which extends from the end face 30. Radial bores 31 run from the end of the blind bore 29 to the outer surface 32 of the end portion 21.

FIG. 1 illustrates the injection procedure and it can be seen that, under the pressure of the molten material which acts on the end portion 20, the end face 30 of the control slide 22 lies against an abutment surface 31 of an end disc 32. The end disc 32, in turn, abuts the inner surface of the nozzle tip 9.

The molten material introduced into the inlet opening 8 of the nozzle flows through the axial bore 24 of the end portion 20, the radial bores 26 and the annular groove 27 into the inner compartment 15 of the nozzle. Since the outer periphery of this inner compartment is bounded by the annular strainer 12, the molten material thereafter flows through the annular gaps 33 delimited by the strainer discs 13. These annular gaps have a width of about 0.25 mm so that larger solid particles are held back in the inner compartment. The molten material flows from the outer compartment 14 into the nozzle passage 10 of the nozzle tip 9 via channels 34 defined by ribs 44 of the front guiding disc 17 (see also FIGS. 8-10) and bores 35 in the end disc 32 (see also FIGS. 13-15). Since, during the injection procedure, the nozzle tip 9 abuts a feeding box bushing 36a of an implement 37a equipped with groups of molds, the molten material from the nozzle passage arrives at the associated group of molds.

To switch the control slide 22 from the terminal position illustrated in FIG. 1 to the terminal position of FIG. 2 corresponding to the cleansing procedure, a pipestem 36 of a switching tube 37, which can be T-shaped or L-shaped, is introduced into the outlet opening 11 and the nozzle passage 10 from the outside. The pipestem 36 fits in the nozzle passage 10 in a fluidtight fashion. In the illustrated exemplary embodiment, the conduit 38 leading to the atmosphere is arranged in a block 39 which abuts the nozzle tip 9 and the feeding box bushing 36a of the implement 37a.

The block 39 is adjusted to the contour of the nozzle tip 9 on one side and to the outer surface 40 of the feeding box bushing on the other side.

When the nozzle is employed as a machine nozzle, the nozzle can be displaced from the implement 37a by a stroke of the machine for the purpose of changing over to the cleansing procedure. The switching tube 37 with the block 39 is then placed against the feeding box bushing 36a. The pipestem 36 is brought into register with the outlet opening 11 and nozzle passage 10, and the nozzle is then moved towards the block 39 until the switched position shown in FIG. 2 has been achieved. During the cleansing procedure, the end face 30 of the end portion 21 of the control slide 22 is thus pressed against the free end face of the pipestem 36 by the pressure of the molten material.

The molten material conveyed to the nozzle is now first conducted into the outer compartment 14, flows through the annular gaps 33 of the annular strainer and enters the inner compartment 15 where the contaminants have accumulated during the injection procedure. Under the pressure of the molten material, these are advanced through the bores of the end portion 21, through the pipestem 39 and through the conduit 38 into the atmosphere.

I claim:

1. An apparatus for filtering flowable material, said apparatus comprising a nozzle, and said nozzle including a housing which defines a chamber, said housing having an inlet and an outlet for the flowable material, and said nozzle further including means for electrically heating said housing, and dividing means in said chamber for dividing said chamber into an inner compartment and an outer compartment surrounding said inner compartment, said dividing means including a strainer for the flowable material, and said nozzle also including a regulating member movable between a first position in which the flowable material entering said inlet is conducted into said inner compartment for flow through said strainer into said outer compartment and a second position in which flowable material entering said inlet is conducted into said outer compartment for flow through said strainer into said inner compartment, said strainer filtering the flowable material when the material is conducted into one of said compartments for flow through said strainer into the other of said compartments.

2. The apparatus of claim 1, wherein said strainer and said inner compartment are substantially annular in shape.

3. The apparatus of claim 1, wherein said regulating member is in register with said outlet, said apparatus further comprising a displacing member for moving said regulating member from one of said positions to the other, said displacing member having a tubular portion which is insertable in said outlet to engage said regulating member and to receive contaminants which are to be withdrawn from said chamber.

4. The apparatus of claim 3, wherein said housing, outlet and regulating member have respective longitudinal axes which are substantially colinear.

5. The apparatus of claim 3, wherein said regulating member is bolt-shaped.

6. The apparatus of claim 3, wherein said tubular portion is receivable in said outlet in a fluidtight manner.

7. The apparatus of claim 3, wherein said displacing member includes a block-shaped portion having a conduit which communicates with said tubular portion and with the atmosphere.

8. The apparatus of claim 7, wherein said displacing member is substantially T-shaped.

9. The apparatus of claim 7, further comprising means for casting the flowable material, said block-shaped portion being designed to bear against said casting means and against said housing.

10. The apparatus of claim 9, further comprising means for moving said housing away from said casting means so that said block-shaped portion can be brought into abutment with said housing by insertion of said tubular portion into said outlet, and into abutment with said casting means.

11. The apparatus of claim 7, further comprising means for casting the flowable material, said block-

shaped portion having a first side which is substantially complementary to a side of said housing in the region of said outlet and a second side which is substantially complementary to a side of said casting means.

12. The apparatus of claim 1, wherein said chamber has two ends and said dividing means includes a guiding member at each of said ends, said regulating member being slidably supported by said guiding members.

13. The apparatus of claim 12, wherein each of said guiding members is provided with a recess, said regulating member including piston-shaped portions which are received in the respective recesses.

14. The apparatus of claim 13, wherein each of said piston-shaped portions is provided with a blind bore, and at least one radial flow channel communicating with the respective blind bore and extending to the periphery of the respective piston-shaped portion, each of said flow channels being arranged to selectively communicate with at least one of said compartments.

15. The apparatus of claim 14, wherein said inlet is located at one end of said chamber in the region of one of said guiding members, said one guiding member being provided with an angular passage which communicates with the respective recess and one of said compartments, and said passage being arranged to communicate with one of said flow channels when said regulating member is in one of said positions.

16. The apparatus of claim 12, wherein said outlet is located at one end of said chamber in the region of one of said guiding members, said apparatus further comprising an abutment member on one side of said one guiding member between said one guiding member and said outlet, said strainer being situated on an opposite side of said one guiding member, and said one guiding member defining a straining gap on said opposite side, said one guiding member further cooperating with said abutment member to define at least one discharge channel connecting said outlet with one of said compartments.

17. The apparatus of claim 16, wherein said straining gap is substantially annular in shape.

18. The apparatus of claim 16, wherein said guiding members and said abutment member are disc-shaped.

19. The apparatus of claim 12, wherein at least one of said guiding members is provided with a plurality of radially projecting ribs which cooperate to define at least one flow channel.

20. The apparatus of claim 19, wherein said outlet is located at the same end of said chamber as said one guiding member.

21. The apparatus of claim 19, wherein said ribs extend to the periphery of said chamber.

22. The apparatus of claim 19, wherein said ribs are in the form of substantially circular segments.

23. The apparatus of claim 1, wherein said strainer comprises a plurality of disc-shaped elements which define straining gaps.

24. The apparatus of claim 23, wherein said strainer and said straining gaps are substantially annular in shape.

25. The apparatus of claim 23, wherein said straining gaps have a width of approximately 0.25 mm.

26. The apparatus of claim 23, wherein each of said disc-shaped elements is provided with a plurality of radially projecting ribs.

27. The apparatus of claim 26, wherein said ribs extend to the periphery of said chamber.

28. The apparatus of claim 26, wherein said ribs are in the form of substantially circular segments.

29. The apparatus of claim 23, wherein each of said ribs projects to one side of the respective disc-shaped element by a distance substantially equal to the width of the straining gap on such side.

30. The apparatus of claim 1, wherein said housing comprises a substantially cylindrical housing portion, and a nozzle tip releasable connectible with said housing portion.

31. The apparatus of claim 30, wherein said housing portion and said nozzle tip are provided with complementary threads.

32. The apparatus of claim 30, wherein said chamber has two ends and said dividing means includes a guiding member at each of said ends, said regulating member being slidably supported by, and said strainer being disposed between, said guiding members, said nozzle tip and one of said guiding members being situated at one of said ends, said apparatus further comprising an abutment member between said nozzle tip and said one guiding member, said abutment member bearing against said nozzle tip.

33. The apparatus of claim 1, wherein said heating means comprises wires which are embedded in said housing, each of said wires being electrically insulated from said housing over substantially the entire length of the respective wire.

34. The apparatus of claim 33, further comprising a current source; and wherein each of said wires has a first end which is connected to said current source and a second end which is connected to said housing.

35. The apparatus of claim 7, wherein said displacing member is substantially L-shaped.

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US00526404A

United States Patent [19][11] **Patent Number:** **5,264,040****Geyling**[45] **Date of Patent:** **Nov. 23, 1993****[54] RAPID-SWITCHING ROTATING DISK REACTOR**[75] **Inventor:** Franz T. Geyling, Austin, Tex.[73] **Assignee:** Sematech, Inc., Austin, Tex.[21] **Appl. No.:** 978,305[22] **Filed:** Nov. 17, 1992**Related U.S. Application Data**

[63] Continuation of Ser. No. 728,433, Jul. 11, 1991, abandoned.

[51] **Int. Cl.:** C23C 16/00; H01L 21/20[52] **U.S. Cl.:** 118/728; 118/730; 437/87; 29/25.01[58] **Field of Search:** 29/25.01; 118/50.1, 118/634, 730, 725, 731, 719, 728; 427/240, 248.1, 300**[56] References Cited****U.S. PATENT DOCUMENTS**

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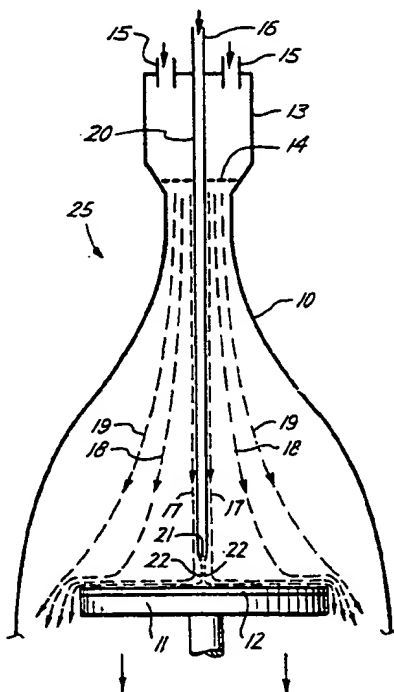
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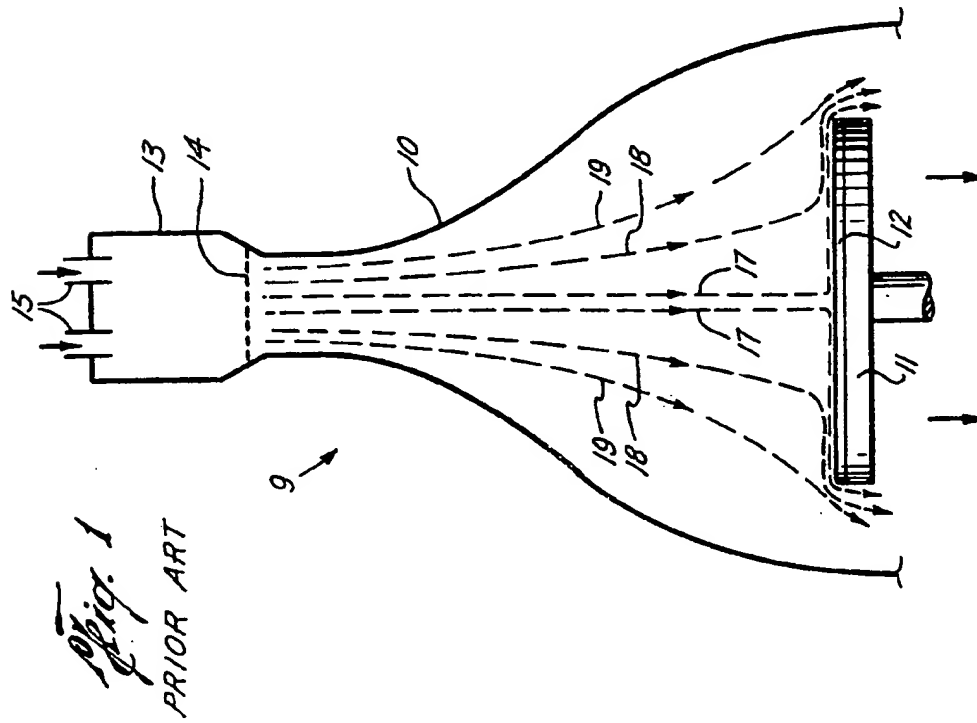
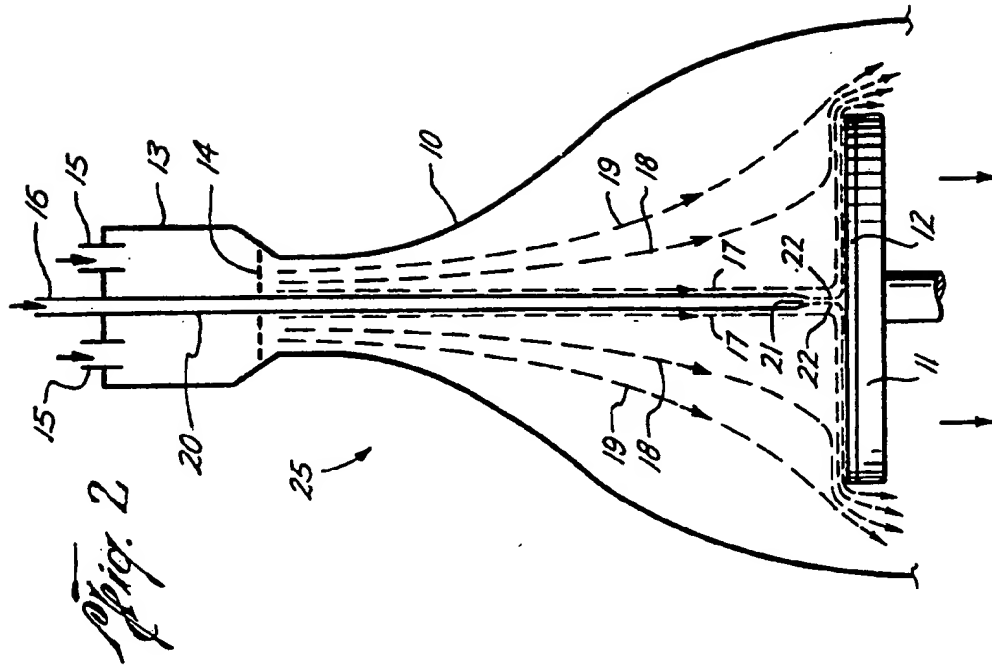
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Primary Examiner—Olik Chaudhuri**Assistant Examiner**—Ramamohan Rao Paladugu**Attorney, Agent, or Firm**—William W. Kidd**[57] ABSTRACT**

A rapid switching rotating disk reactor has an elongated injector for injecting an inert gas into the chamber of a rotating disk reactor. The nozzle of the injector is proximate to the center of the rotating wafer for the purpose of providing an inert gas flow to produce an inert gas boundary layer above the wafer. Whenever the environment of the chamber is to be changed by an introduction of another fluid medium, the injector is activated to provide an inert boundary layer atop the semiconductor wafer, wherein any processing caused by the reactive gases in the chamber is prevented from occurring. Once the chamber is filled with the subsequent fluid medium, the injector is turned off in order for the next processing to commence.

10 Claims, 1 Drawing Sheet.



RAPID-SWITCHING ROTATING DISK REACTOR

This application is a continuation, of application Ser. No. 728,433, filed Jul. 11, 1991 now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of semiconductor manufacturing techniques and, more particularly, to an apparatus for processing a semiconductor wafer.

2. Prior Art

In a typical semiconductor integrated circuit fabrication process, integrated circuit devices are constructed onto a preformed semiconductor wafer. These wafers are typically flat and circular in shape. For silicon semiconductor wafers, the diameter of the current wafers vary from approximately four inches to eight inches. By utilizing a number of various processing techniques, which may include doping, implanting, depositing, etching, to name a few, a number of completed integrated circuit "chips" are formed on a given wafer. Subsequently, the wafer is cut to separate each independent chip and then packaged for use.

Due to the trend towards the use of larger diameter wafers and the continued transition toward submicron-dimensioned features, the semiconductor industry is moving toward a single wafer processing technique, instead of the batch processing technique well-known in the prior art for processing smaller diameter wafers. In a typical single wafer processing technique for depositing and/or etching various wafer layers, a single wafer is typically disposed onto a wafer platen ("chuck"), which is typically resident in an enclosed reactor chamber. In order to perform the various depositing and/or etching steps in the manufacture of integrated circuits, various gases are introduced into the reactor chamber under preselected chamber environment to deposit or etch a given layer on the wafer.

With the advent of submicron-dimensioned features, it has become critical to control the tolerances of the various processes in order to control the minute dimensions required of various devices and interconnecting lines in or on the wafer. The construction of the particular reactor chamber, as well as the various processing parameters, such as chamber pressure, gas flow, gas mixture, etc., play a critical role in providing for the submicron-dimensioned features. Thus, many of the prior art reactors are incapable of providing for such tolerances to fabricate submicron-dimensioned integrated circuit devices.

One type of a specialized reactor is a rotating disk reactor (RDR). A RDR includes a reactor chamber with a wafer platen or chuck resident therein. However, unlike other reactors, the wafer chuck of the RDR rotates at a high rate of speed. The rotation of the chuck and the wafer provides for a uniform gas or plasma flow over the wafer which resides atop the chuck. The RDR is exceptionally useful when a thin layer is to be deposited onto the wafer. RDR technology is well-known in the prior art and one such RDR is manufactured and sold by EMCORE Corporation of Somerset, N.J.

One disadvantage of prior art RDRs is the inability of the RDR to switch rapidly from one process gas to another. That is, when one gas mixture is to be replaced by a second gas mixture in the chamber for a subsequent processing step, a finite amount of time is required for

the internal environment of the chamber to change completely from the first gas mixture to the second. Unfortunately, reactions continue to occur on the wafer while the gas mixtures are being interchanged and, in many instances, this continued processing is uncontrollable.

Accordingly, it is appreciated that what is desired is a rotating disk reactor which has the capability of subjecting the wafer to rapid switching between the processing gases.

SUMMARY OF THE INVENTION

A rapid switching rotating disk reactor is described in which an elongated injector injects an inert gas onto a wafer which resides on a rotating wafer chuck. The nozzle of the injector is proximal to the center of the rotating wafer for the purpose of providing an inert gas flow to produce an inert gas boundary layer above the wafer as the gas flows from the center to the periphery of the wafer.

At anytime in which the wafer is to be isolated from the reactive fluid medium in the chamber, the inert gas is activated to form a boundary layer. The boundary layer operates as an isolating medium by isolating the reacting fluid from the wafer. The mass and the rate of flow of the inert gas are of sufficient values to prevent the cross-diffusion of reactants across the boundary layer.

In one example, a deposition/etch process requires one gas for deposition while a second gas is used for etching. After the deposition step is completed, the injector is used to activate the inert gas to form the boundary layer. After the evacuation of the first gas, the second gas is introduced into the chamber. Then, the inert gas is turned off in order for the etching process to occur. Although, a notable time lapse will be encountered to replace the chamber with the second gas, the wafer will actually experience a rapid switching (an almost instantaneous change between the two gases.)

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a prior art rotating disk reactor.

FIG. 2 is a cross-sectional view of a rotating disk reactor of the present invention which utilizes a neutral gas injector for rapid switching.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An apparatus and method for processing a single semiconductor wafer in a rotating disk reactor is described. In the following description, numerous specific details are set forth, such as specific materials, structures, processes, etc., in order to provide a thorough understanding of the present invention. However, it will be obvious to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known processes and structures have not been described in detail in order not to unnecessarily obscure the present invention.

Prior Art

Referring to FIG. 1, a prior art rotating disk reactor (RDR) 9 is shown. The reactor 9 is comprised of a mixing chamber 13, diffuser screen 14 and reactor chamber 10 for processing a semiconductor wafer 12, which is resident on a wafer platen 11. The wafer platen 11 is commonly referred to as a "chuck" and is resident

in reactor chamber 10. The purpose of chambers 10 and 13 is to provide an enclosed container for containing the various gases required in the processing of wafer 12.

In order to introduce the various gases, openings 15 are provided at the upper end of mixing chamber 13 for the injection of such gases. In the specific example of FIG. 1, two gas supply openings 15 are shown in the upper end of the mixing chamber 13. As is shown, a first gas mixture is introduced through the first of the openings 15, while a second gas mixture is introduced through the second of the opening 15.

The gases from the two openings 15 enter the mixing chamber 13 and combine to form a homogeneous nutrient. The homogeneous nutrient is diffused as it passes the diffuser screen 14, which is disposed between the two chambers 13 and 10. The diffused nutrient then enters the reactor chamber 10. It is to be appreciated that the details of the structures of the mixing chamber 13 and diffuser screen 13 are a design choice and various schemes can be readily implemented to introduce and mix the desired gases.

The chuck 11, which is circular in shape to accommodate a circular semiconductor wafer 12, resides at the lower, or enlarged, end of reactor chamber 10. In a typical RDR reactor, chuck 11 is made to rotate at a high rate of speed in the approximate range of 800-2000 rpm. Wafer 12 resides upon chuck 11 and is clamped to chuck 11 by vacuum inlets or by a close-fitting recess.

In operation, a first gas is introduced, such as by injection, through the first of the openings 15 upon the commencement of a given processing step, such as the depositing of a formation layer onto wafer 12. Due to the force of the gas being injected and the lower pressure caused by an exhaust pump (not shown) coupled to the lower end of chamber 10, the gas mixture tends to flow downward in the reactor chamber 10. The path of this gas flow is approximately illustrated by dashed lines 17, 18, and 19 in FIG. 1. Because of the rotation of the wafer 12, gases impinging onto the wafer 12 are forced toward the outer edge of the wafer, primarily due to the centrifugal force exerted by the rotating action of the wafer 12. This action allows for a uniform flow of the gas nutrients across the surface of the wafer 12, thereby providing for a substantially uniform gas layer across the exposed surface of the wafer 12 in order to perform the desired processing. The operation of such a RDR 9 is well known in the prior art and one such reactor is available from the aforementioned EMCORE Corporation.

When a desired thickness has been deposited onto wafer 12 during this particular processing step, the gas flow through the first opening 15 is terminated in order to proceed with the subsequent processing step. A successive processing step typically requires the introduction of a different reactant into chamber 10. When the next processing step is to commence, a second gas mixture is introduced, such as by injection, through the second of the openings 15 into chamber 13. Again, with the desired gas flow illustrated by the dashed lines 17, 18, and 19, the subsequent processing step occurs in chamber 10. For example, this second process may be an etching step in a combined deposition/etching (dep-/etch) process.

One significant disadvantage of the prior art RDR 9 is the time required to completely replace the first gas in the chamber with the second gas. What is desired is an abrupt, instantaneous, transition (simultaneous switching) of the gas content in chamber 10. However, in a

prior art RDR 9, some finite amount of time is required to completely replace the first gas mixture in the chamber with the second gas mixture. During this transition period, undesirable processing of the wafer 12 by the first gas may continue which processing may be nonuniform, unpredictable and uncontrollable, due to the complex transient flow conditions of the chamber 10. For the growth of very thin layers, for example germanium on silicon or formation of group III-V hetero-structures, such transition times are undesirably long and can cause irregular interface growth on wafer 12.

It is to be noted that although two openings 15 are shown in FIG. 1, it is for exemplary purposes only. The actual number of openings is a mere design choice. Furthermore, for any given process step a number of different gases can be introduced into chamber 13 through a plurality of openings for mixing in chamber 13. For example, with the RDR 9 of FIG. 1, two different gases can be injected into chamber 13, each gas through a separate opening 15, and mixed in chamber 13.

Present Invention

In order to overcome the undesirable transitions of the prior art rotating disk reactor, a rapid switching rotating disk reactor 25 of the present invention is utilized. Referring to FIG. 2, the rotating disk reactor (RDR) 25 of the present invention is shown. Although a variety of alternative reactor configurations can be readily utilized, the structure of the prior art reactor 9 is duplicated in FIG. 2 for ease of understanding the present invention. Again, two openings 15 are shown but the actual number of such openings 15 is a design choice.

Reactor 25 is comprised of mixing chamber 13, openings 15, diffuser screen 14, reactor chamber 10 and chuck 11 which has a semiconductor wafer 12 resident thereon. In addition, reactor 25 includes an injector 20, which enters chamber 13 through opening 16 and substantially extends the length of the reactor chambers 10, and 13 to have a nozzle opening 21 proximate to the center of the wafer 12. Opening 16 is centrally located and is of sufficient size to permit the passage of injector 20 but provides a seal to prevent the escape of gas from the chamber 13. One of the purposes of injector 20 is to provide for the injection of an inert gas, such as argon, under pressure onto the surface of wafer 12. The purpose of the inert gas is to provide for a boundary layer on the surface of wafer 12 as is shown by dotted line 22 in FIG. 2.

In operation, a fluid, such as a gas or a gas mixture, is introduced into mixing chamber 13 through openings 15, as was the case in the prior art reactor 9 of FIG. 1. The gas nutrient is then diffused and introduced into reactor chamber 10. The introduction of this gas nutrient is shown by dotted lines 17, 18, and 19 in FIG. 2. This particular processing of the gas nutrient is equivalent to that process which takes place in the prior art reactor 9 of FIG. 1. However, when the first processing step is completed, the inert gas is introduced into the chamber 10 by injector 20. The flow of the inert gas from a nozzle 21 of injector 20 is of sufficient force to provide an inert gas boundary (or barrier) layer 22 above wafer 12. Due to the rotation of wafer 12, this boundary layer 22 of inert gas is substantially uniform over the complete wafer.

It is to be appreciated that this boundary layer 22 must be of sufficient thickness and of sufficient flow in

order to prevent the cross-diffusion of reactants during the typical transit time of the inert gas from the center to the periphery of the wafer disk. As long as the fluid of the first processing step in chamber 10 does not diffuse across this boundary layer 22 onto wafer 12, any processing due to the presence of the first fluid will have ceased on the wafer surface.

Subsequently, a second fluid mixture (i.e., second gas nutrient) is introduced into chamber 10 in order to perform the subsequent processing step. However, unlike the prior art reactor of FIG. 1, the present reactor 25 continues to provide the flow of inert gas from nozzle 21 in order to maintain the inert boundary layer 22 above wafer 12. When the interior of the chamber 10 reaches the desired environment for the second fluid to perform the subsequent processing step, the inert gas flow from injector 20 is stopped. When the inert gas flow ceases, the boundary layer 22 is no longer present above wafer 12 thereby permitting the second fluid to contact the surface of wafer 12. Thus, by the introduction of an inert gas boundary layer 22 above wafer 12, abrupt switching from one fluid mixture contacting the wafer 12 to the second mixture contacting wafer 12 can be achieved.

Although the actual elapsed time required to vacate chamber 10 of the first fluid and fill chamber 10 with the second fluid may actually take several seconds, the wafer itself is not subjected to the fluid transition period occurring within chamber 10. Wafer 12 actually experiences a abrupt switching from the first fluid mixture to the second fluid mixture, due to the blocking effect of the boundary layer 22.

As was previously noted, it is essential that the inert gas flow blocks any cross-diffusion of reactants during the typical transit time of the inert gas from the center to the periphery of the wafer 12. The amount of inert gas flow, as well as the thickness of the boundary layer, will depend on the particular chemical being utilized as the reactant in chamber 10, as well as the physical parameters such as the diameter of the wafer 12 and the speed of rotation of chuck 11.

One example is provided for an illustrative purpose only. In this example, selective metal deposition is achieved by chemical vapor deposition with the use of a cyclic deposition/etch technique. A number of such techniques are well-known in the prior art. For example, in order to deposit metal on a 200 mm (8 inch) wafer disk, an argon gas barrier layer 22 of 1 to 2 cm thickness will need to be deployed. The necessary flow rate of the injected argon will be in the order of 20-60 liters per minute. It is to be appreciated that this is an example only and is not provided for the purpose of limiting the invention. Use of other gases will also necessitate other parameters in order to provide a sufficient blocking layer 22 by the injected inert gas.

It is to be further appreciated that in order to provide a sufficient boundary layer 22 for a variety of reactions, injector 20 can be made adjustable. Typically for a fixed injector 20, the nozzle 21 is positioned 1 to 3 cm above the wafer 12. But, by selectively adjusting the distance of nozzle 21 from wafer 12 for a given process reaction, the boundary layer 22 can be made to vary in order to provide sufficient boundary layer thickness for different reactions. Furthermore, this adjustability of the nozzle distance can be combined with the rate of flow of the inert gas from nozzle 21 in order to provide a rapid-switching RDR which is capable of being readily

adapted to a variety of processing reactions which are to occur in the RDR chamber.

In this alternative embodiment, injector 20 can be made to move perpendicularly in relation to wafer 12 such that the distance from nozzle 21 and wafer 12 can be varied during gas injection and can provide additional flexibility in controlling the boundary layer 22.

The present invention uses quartz or stainless steel as material for injector 20. However, it is to be noted that other non-reactive materials can be readily used also. Furthermore, it is to be appreciated that various processes capable to be used in the RDR 9 of the prior art can be readily adapted for use with the RDR 25 of the present invention.

I claim:

1. An apparatus for processing a semiconductor wafer, comprising:

a housing for providing an enclosed environment for containing reactive processing fluid in order to process said semiconductor wafer;

a rotating chuck, coupled to said housing and having said semiconductor wafer resident thereon, for rapidly rotating said semiconductor wafer;

injector means, coupled to said housing and having its nozzle disposed proximate to an exposed surface of said semiconductor wafer and positioned substantially at the center of said rotating chuck, for injecting nonreacting gas under pressure in order to provide a continuous flow of said nonreacting gas to form an inert boundary layer on said exposed surface of said semiconductor wafer, such that said continuous flow of said nonreacting gas is of sufficient flow rate to form and maintain said inert boundary layer to inhibit cross-diffusion of said processing fluid to said semiconductor wafer, wherein causing said processing of said semiconductor wafer to be interrupted;

said nonreacting gas being continuously injected to maintain said inert boundary layer until said processing fluid is removed from said housing.

2. The apparatus of claim 1 wherein said nonreacting fluid is an inert gas.

3. The apparatus of claim 2 wherein said injector means is an elongated tube extending perpendicularly to have its nozzle substantially adjacent to said exposed surface of said semiconductor wafer.

4. The apparatus of claim 3 wherein said injector means is made of quartz.

5. An apparatus for processing a semiconductor wafer, comprising:

a reactor having a chamber for providing an enclosed environment for containing reactive processing gas mixture in order to process said semiconductor wafer;

a rotating disk, coupled to said chamber and having said semiconductor wafer resident thereon, for rapidly rotating said semiconductor wafer to disperse said processing gas mixture uniformly across a processing surface of said semiconductor wafer due to its rotation;

an injector, coupled to said chamber and having its nozzle disposed proximate to said processing surface and positioned substantially at the center of said semiconductor wafer, for injecting nonreacting gas under pressure in order to provide a continuous flow of said nonreacting gas to form an inert gas boundary layer on said processing surface of said semiconductor wafer, such that said continu-

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ous flow of said nonreacting gas is of sufficient flow rate to form and maintain said inert gas boundary layer to inhibit cross-diffusion of said processing gas mixture to said semiconductor wafer, wherein causing said processing of said semiconductor wafer to be interrupted;

said nonreacting gas being continuously injected to maintains aid inert boundary layer until said processing gas mixture is removed from said chamber.

6. The apparatus of claim 5 wherein said nonreacting gas is an inert gas.

7. The apparatus of claim 6 wherein said injector is an elongated tube extending perpendicularly to have its nozzle substantially adjacent to said processing surface of said semiconductor wafer.

8. The apparatus of claim 8 wherein the rotation of said rotating disk is at least 800 revolutions per minute in order to provide for uniform flow of said inert gas over said semiconductor wafer.

9. The apparatus of claim 8 wherein said injector is made of quartz.

10. The apparatus of claim 8 wherein said injector is made of stainless steel.

* * * * *

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO : 5,264,040
DATED : November 23, 1993
INVENTOR(S): Franz T. Geyling

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 3, line 16, "1o" should be --10--.

Column 7, line 9, "maintains aid" should --maintain said--.

Signed and Sealed this

Twenty-ninth Day of July, 1997

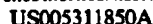


Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks



[11] Patent Number: 5,311,850

[45] **Date of Patent:** **May 17, 1994**

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Primary Examiner—Carl S. Miller

Attorney, Agent, or Firm—Woodard, Emhardt, Naughton, Moriarty & McNett

[57] **ABSTRACT**

A fuel injection system having a novel electromagnetic actuated fuel pump in which four pumping elements, equally-spaced around a camshaft are mounted such that a pair of opposed pumping elements alternate to deliver pressure to a high pressure common rail with a second pair of the pumping pair of pumping elements. In one embodiment of the invention, the pumping process is mechanically actuated, and in another is electronically actuated. The high pressure common rail is adapted to reduce surges in the fuel pressure from the pump by using central and side chambers connected with cross-drilled orifices. The common rail has a relief valve for safety protection not to allow the pressure in the rail to exceed the maximum preset pressure. The electromagnetic injector has a pressure balanced control valve to control fuel flow to the nozzle and has a pressure assistance mechanism at the end of injection to obtain a sharp end of injection. Also, at the beginning of the next injection, the needle opening can be slowed down to meet the engine requirements.

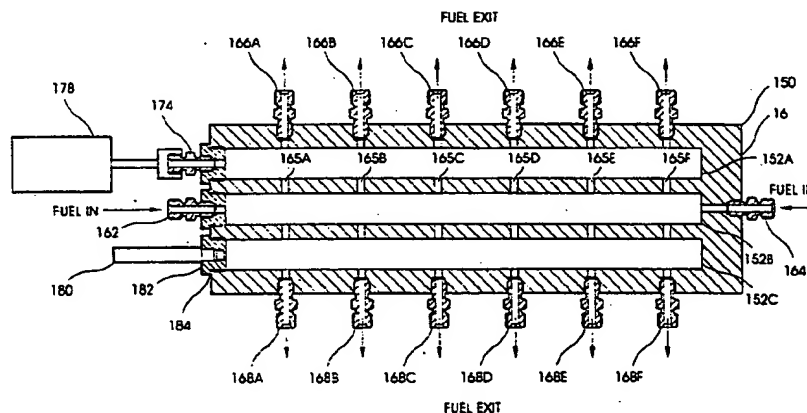
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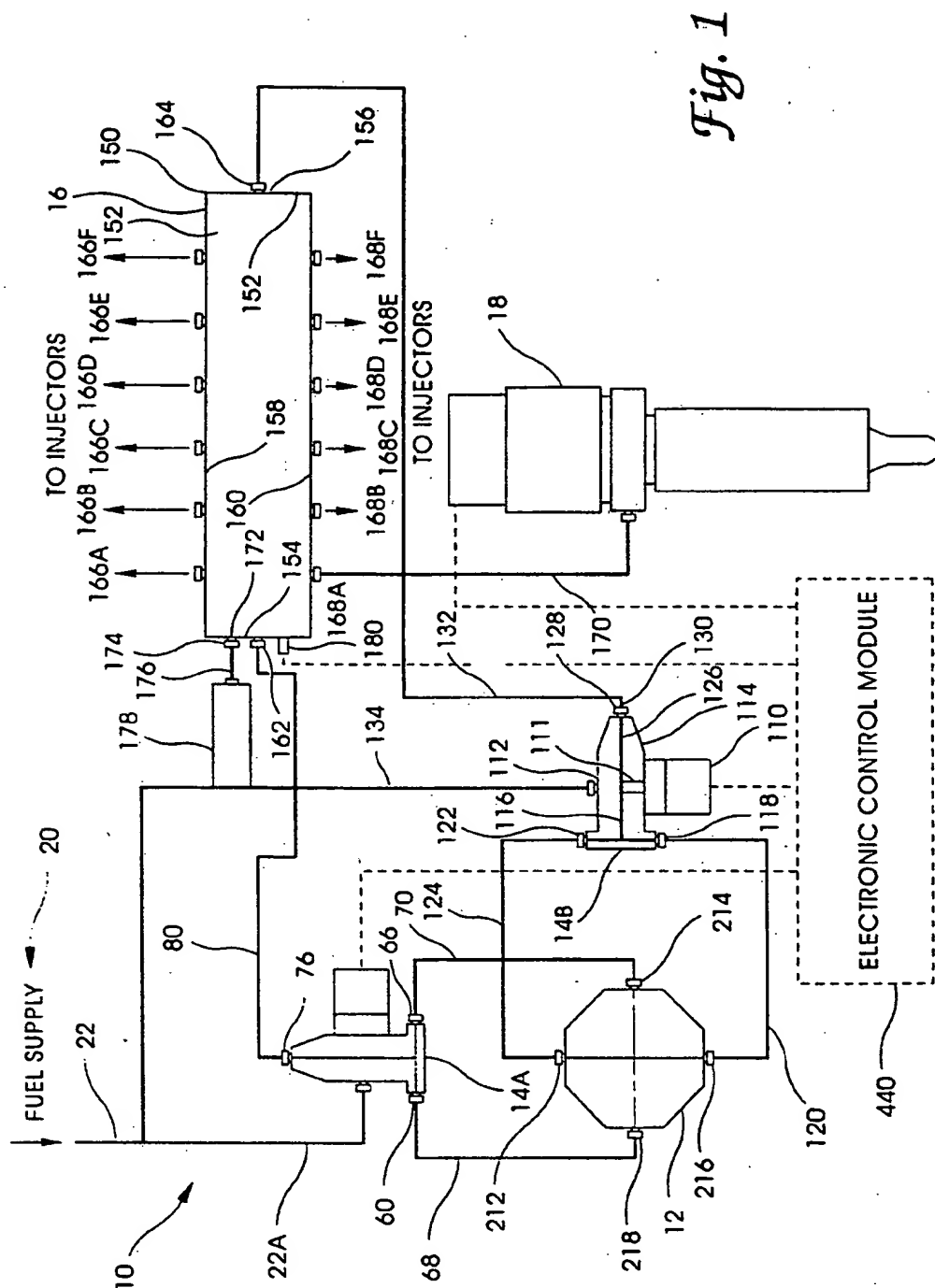
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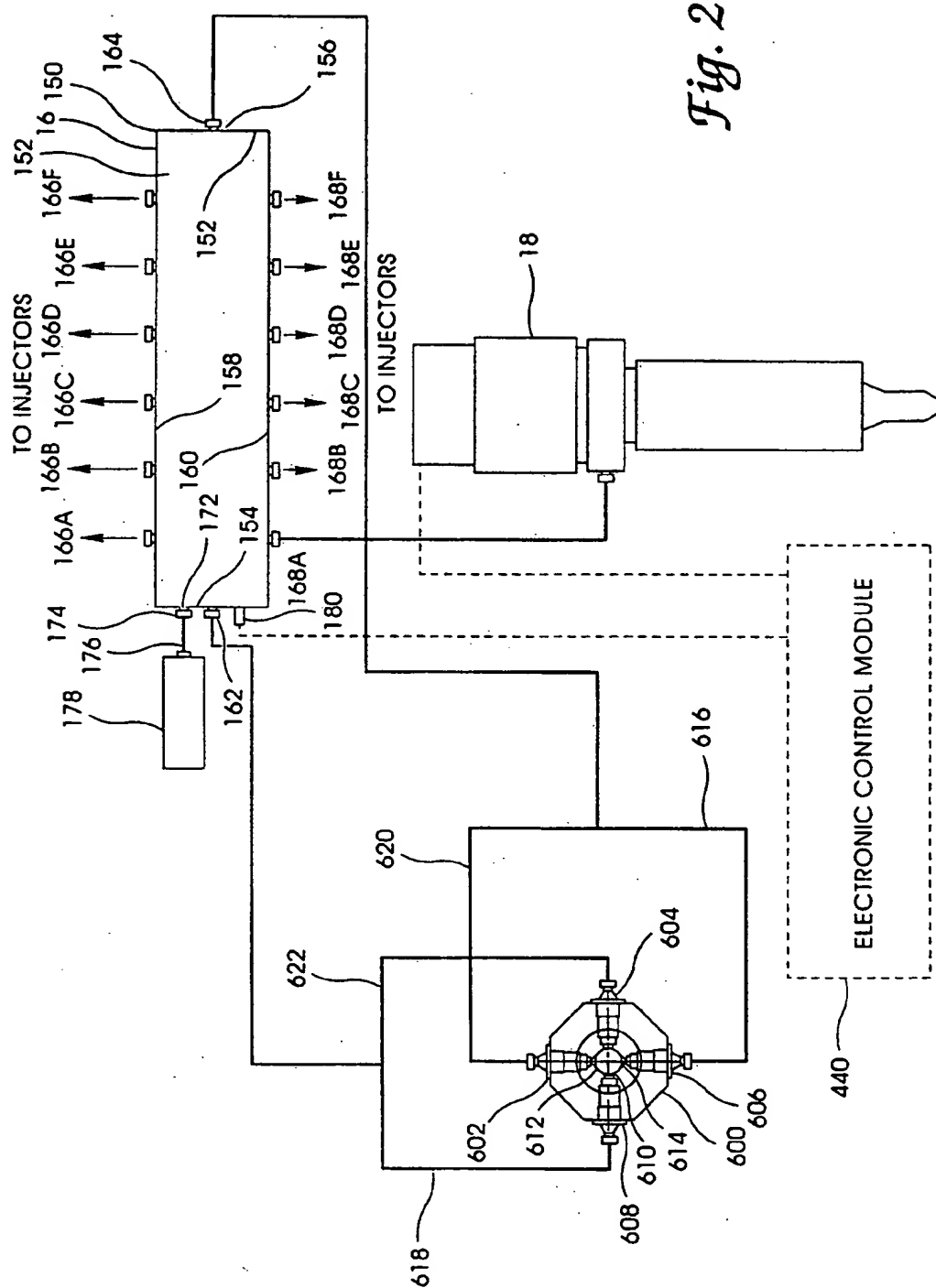
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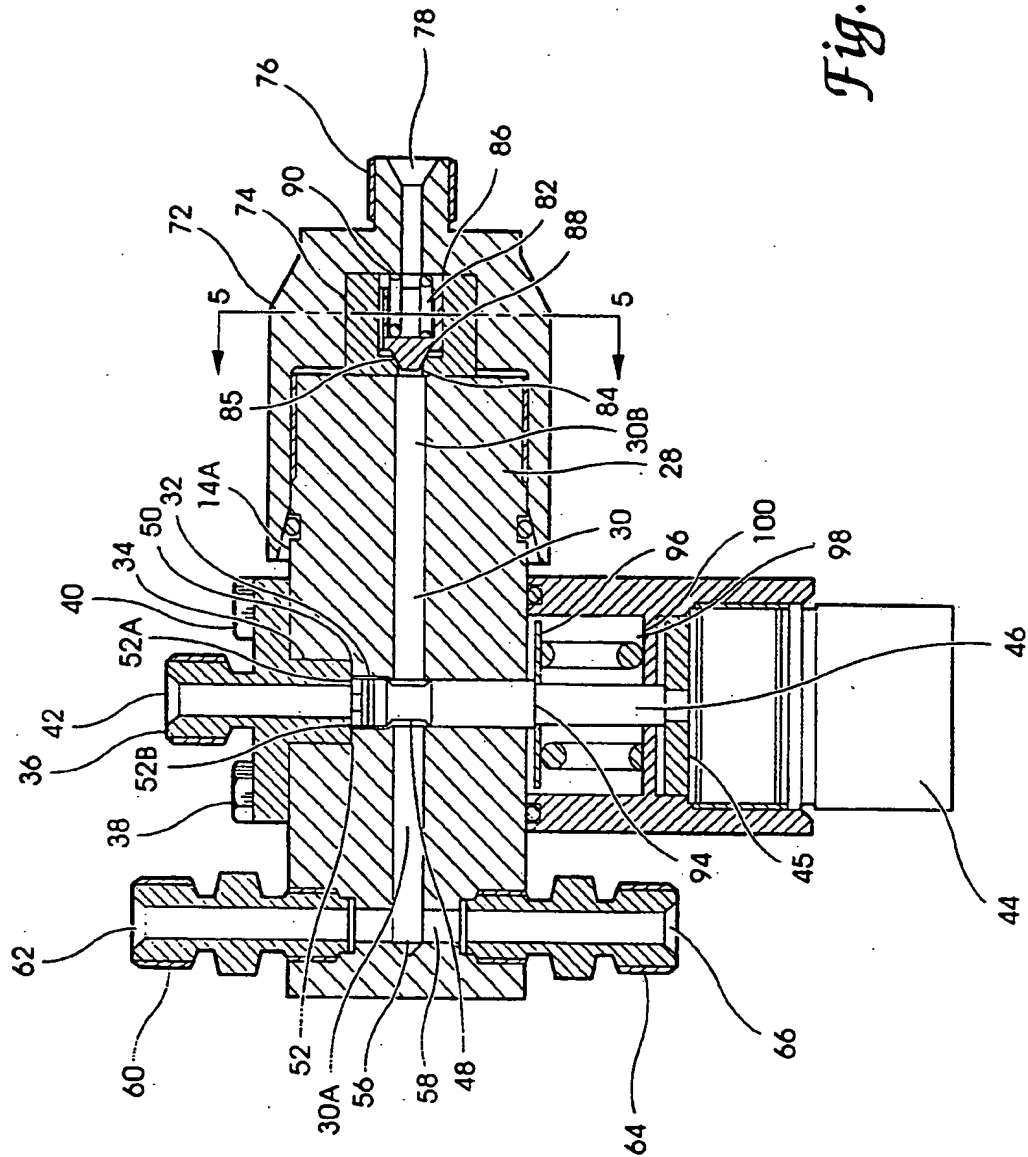
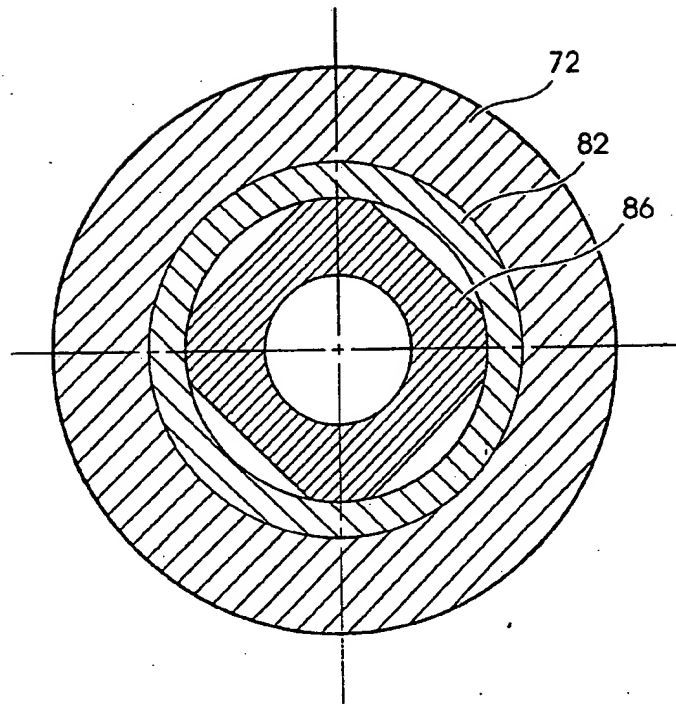


Fig. 4

*Fig. 5*

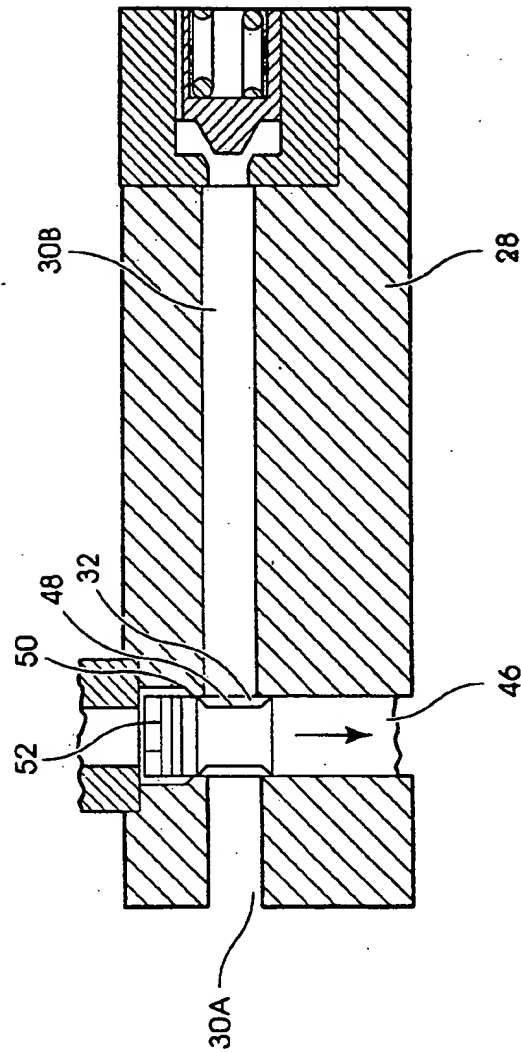


Fig. 5A

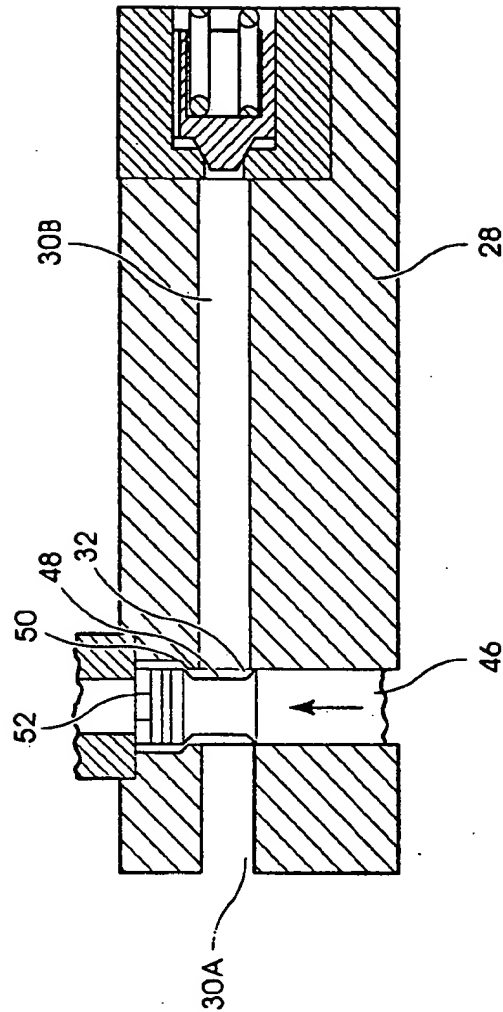


Fig. 5B

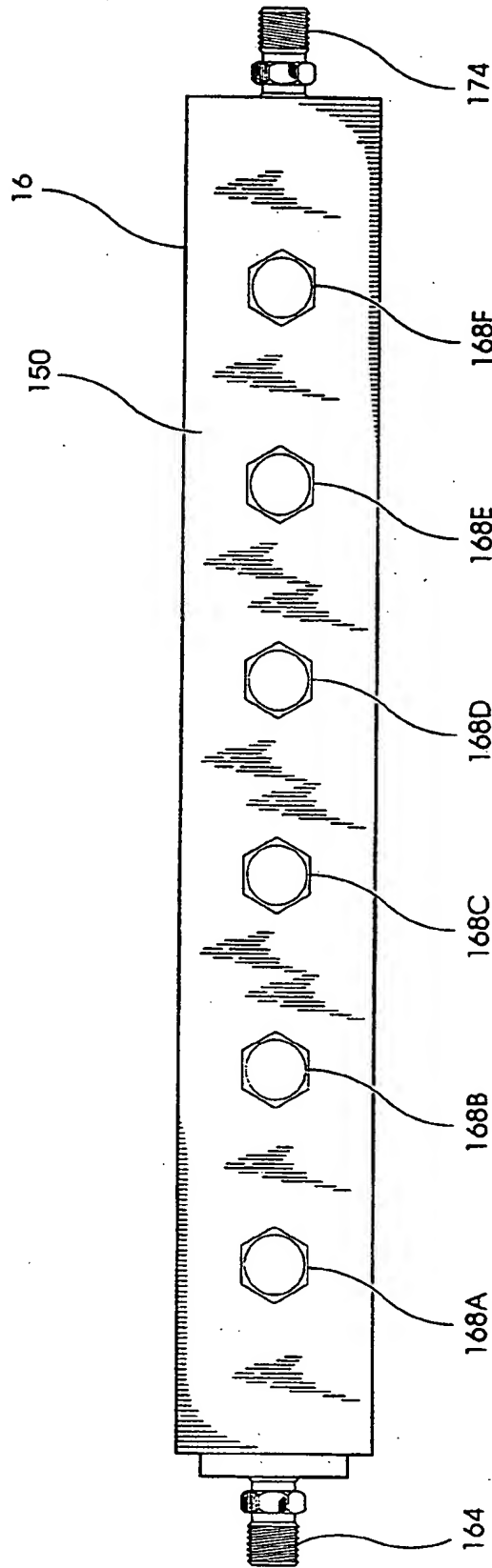


Fig. 6

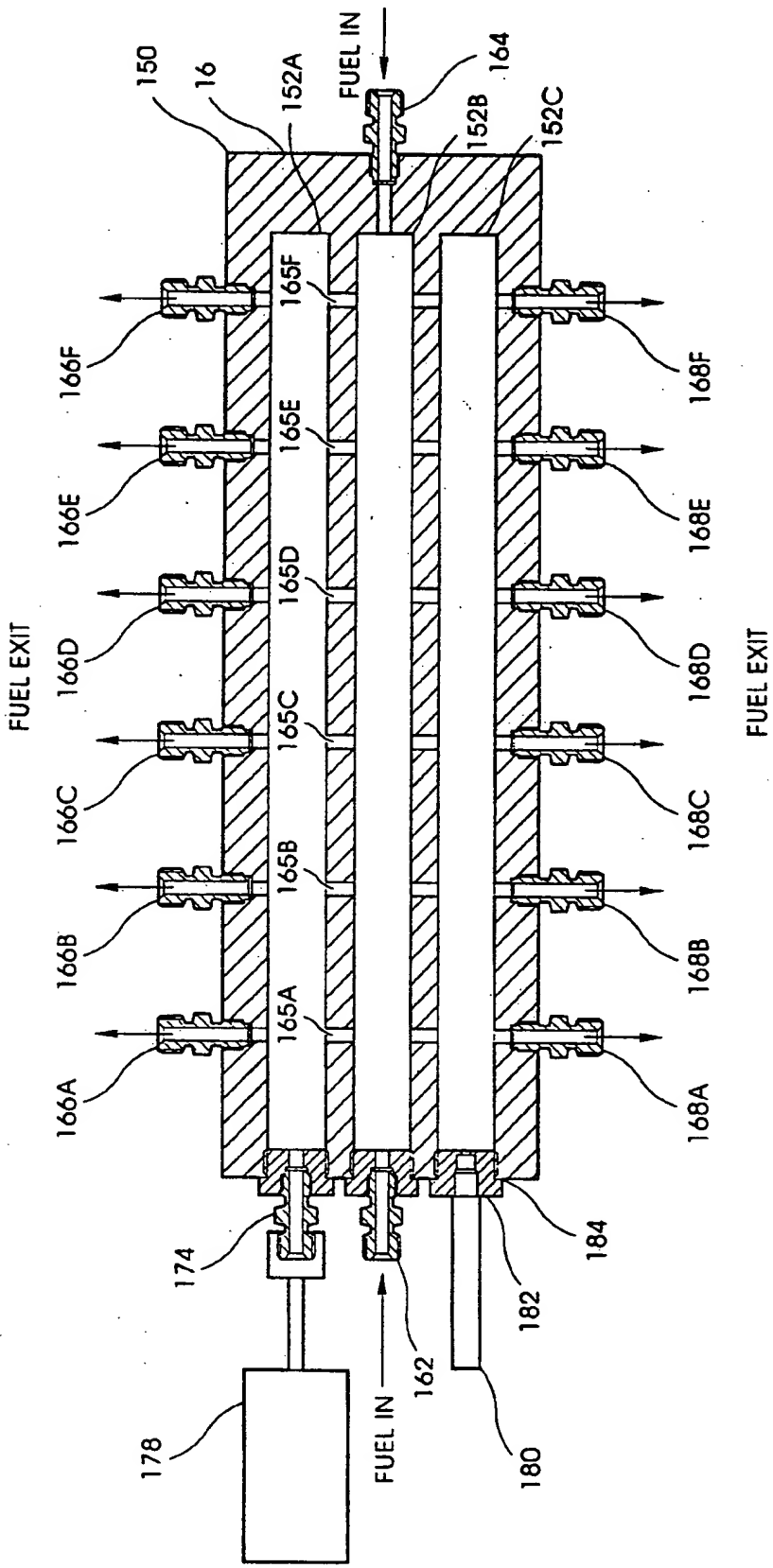
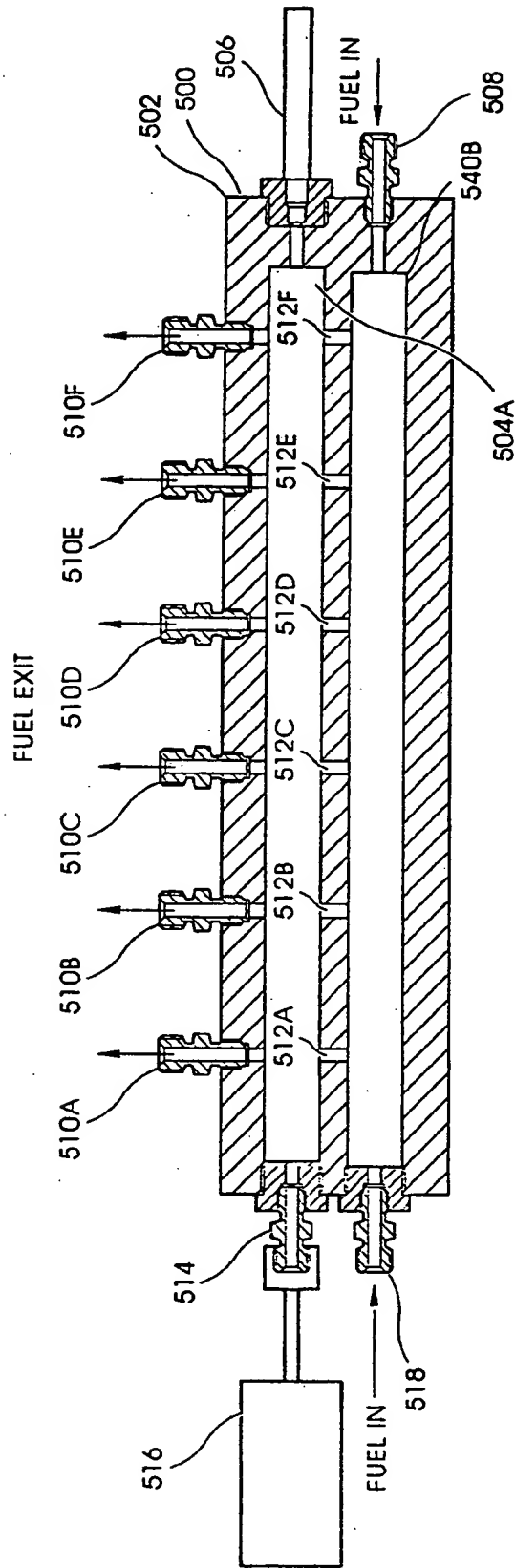
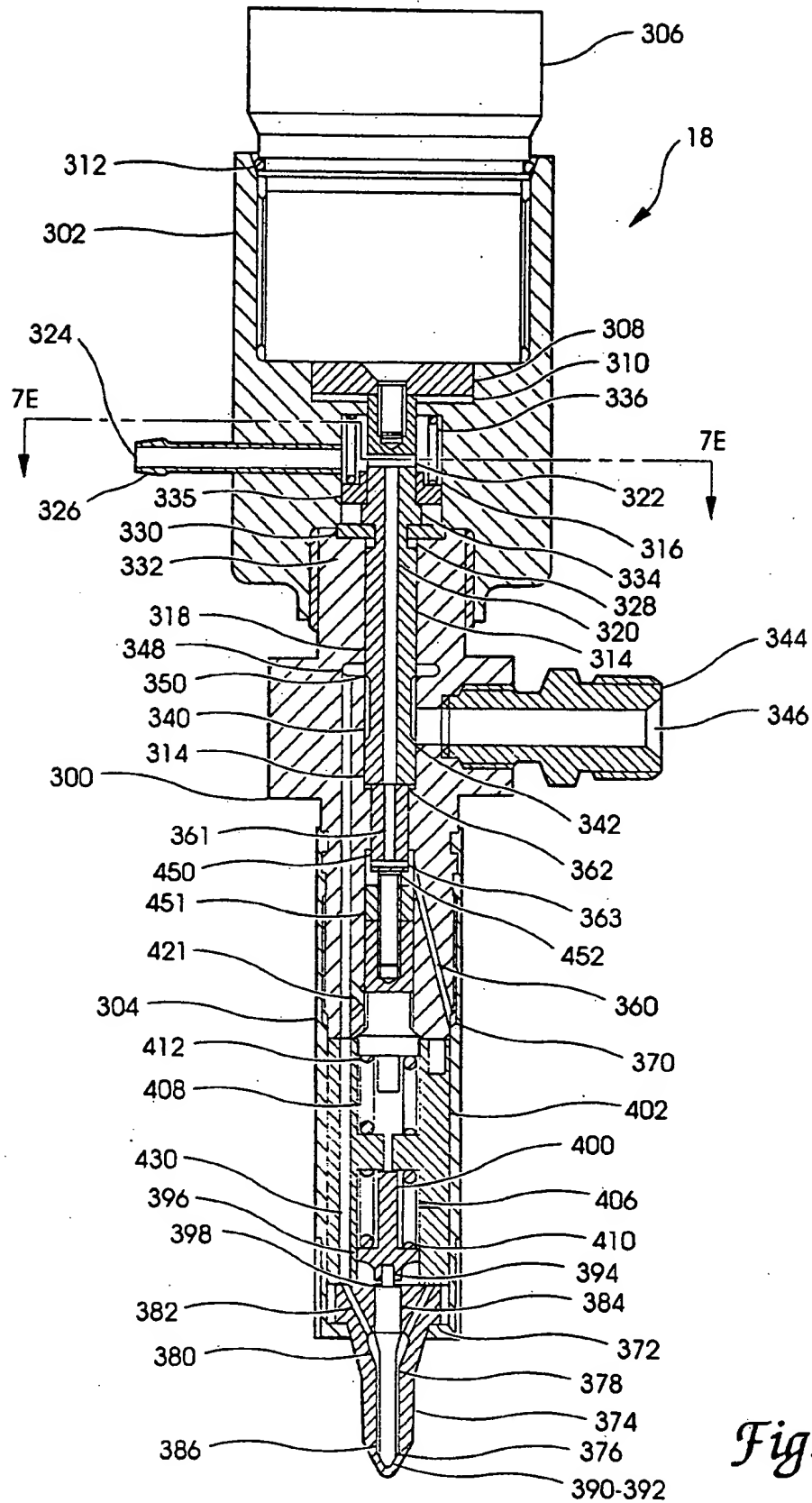


Fig. 6A

*Fig. 6B*

*Fig. 7*

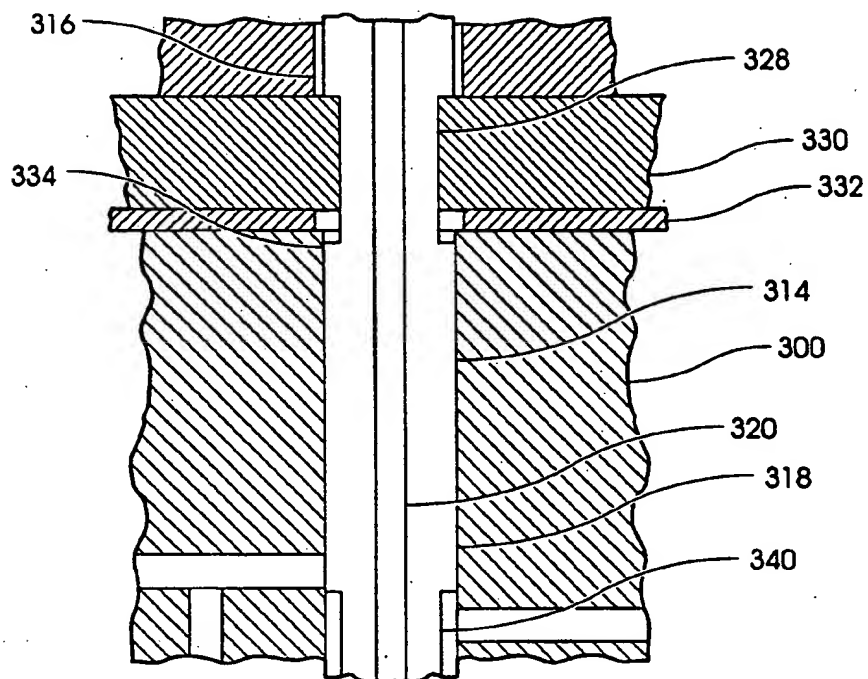


Fig. 7A

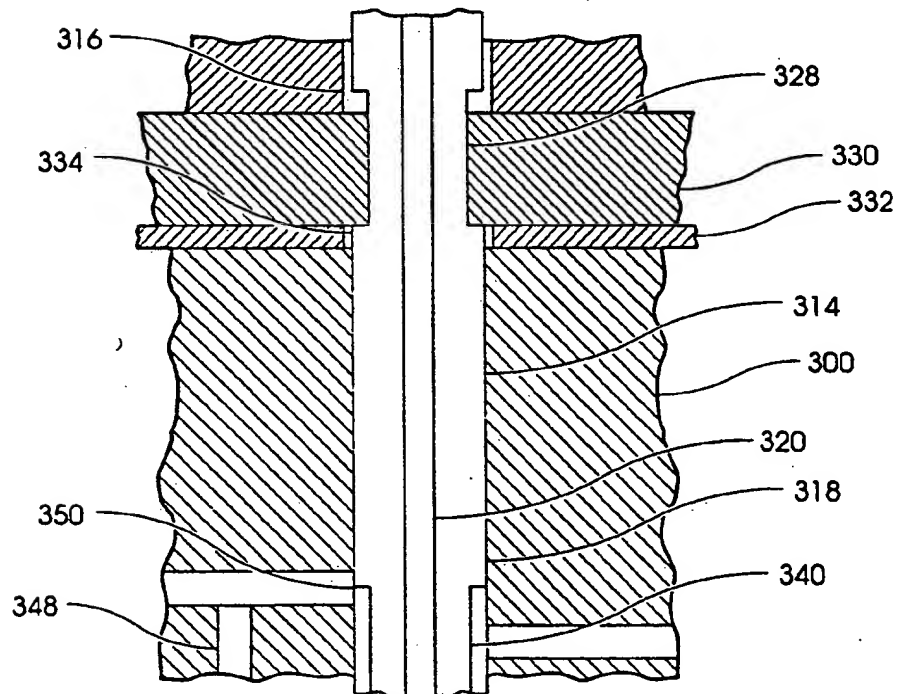
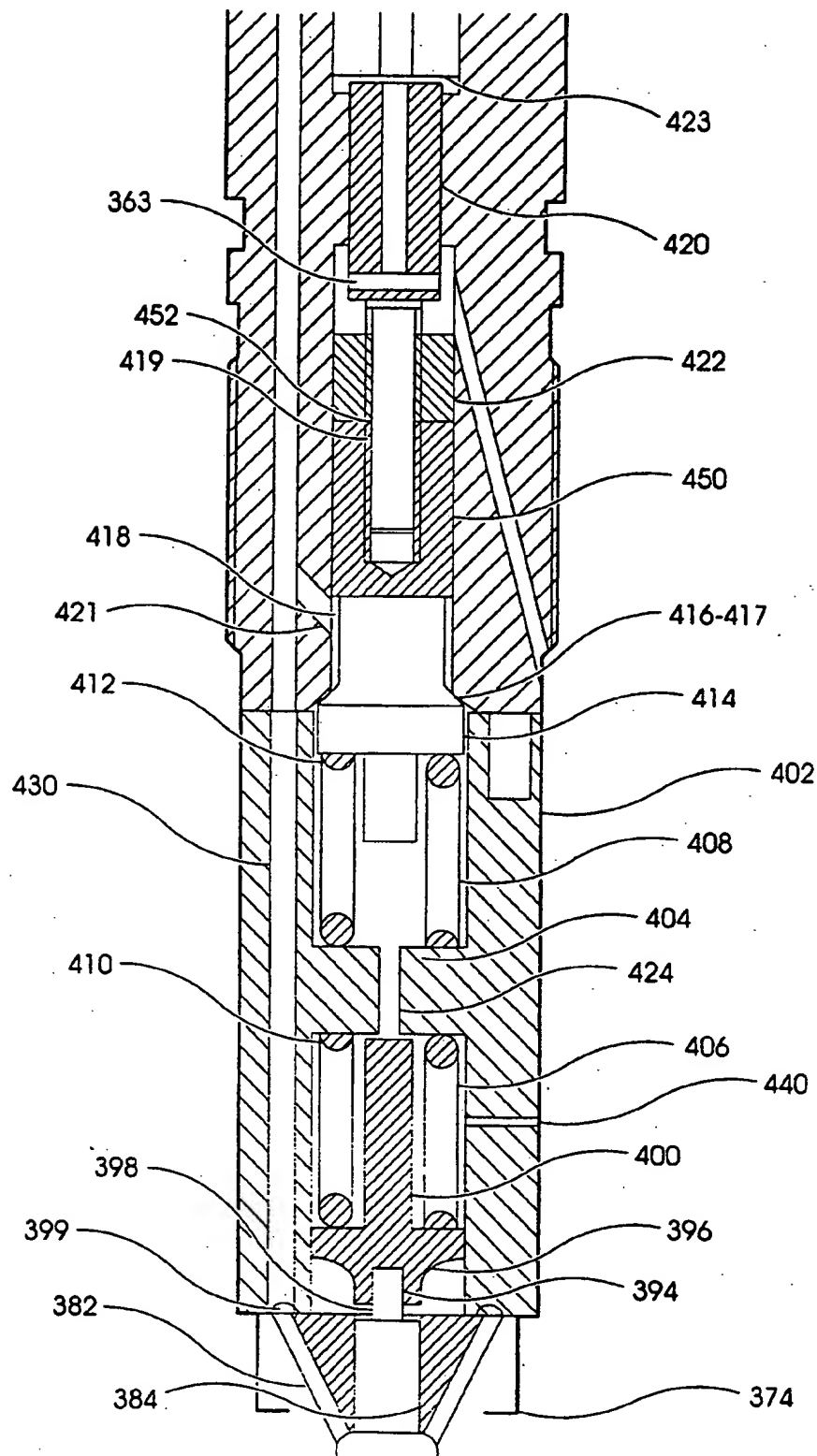
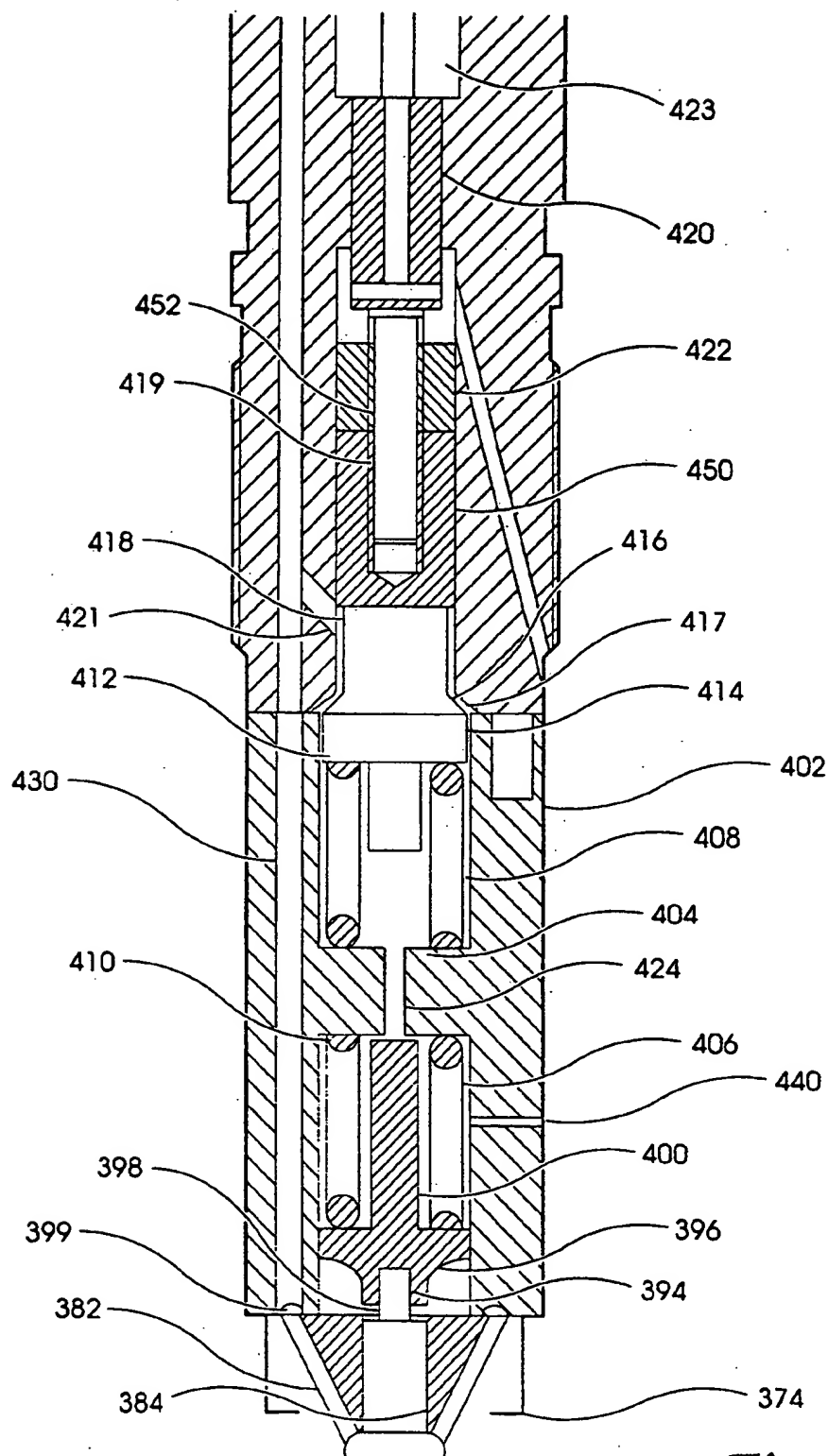


Fig. 7B

*Fig. 7C*

*Fig. 7D*

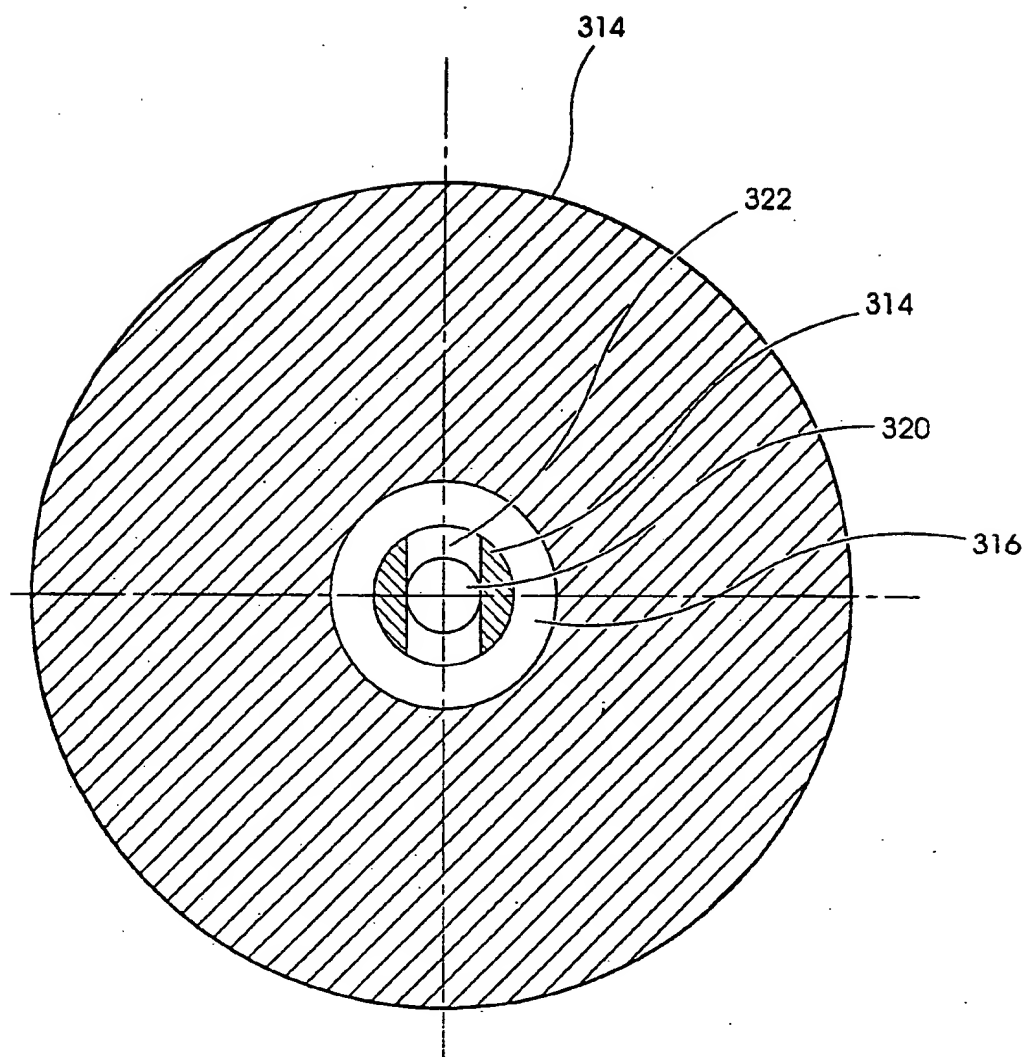


Fig. 7E

HIGH PRESSURE ELECTRONIC COMMON-RAIL FUEL INJECTION SYSTEM FOR DIESEL ENGINES

REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of pending U.S. patent application Ser. No. 07/508,068, filed Apr. 11, 1990, which is a divisional application of U.S. patent application Ser. No. 07/295,588, filed Jan. 11, 1989, now abandoned.

BACKGROUND OF THE INVENTION

This invention is related to a high-pressure, common rail, fuel injection system for injecting metered amounts of highly pressurized fuel into the cylinder of a diesel engine.

Conventional fuel injection systems employ a "jerk" type fuel system for pressurizing and injecting fuel into the cylinder of a diesel engine. A pumping element is actuated by an engine-driven cam to pressurize fuel to a sufficiently high pressure to unseat a pressure-actuated injection valve in the fuel injection nozzle. In one form of such a fuel system having an electromagnetic unit injector, the plunger is actuated by an engine driven cam to pressurize the fuel inside the bushing chamber when a solenoid is energized and the solenoid valve is closed. The metering and timing is achieved by a signal from an electronic control module (ECM) having a controlled beginning and a controlled pulse. In another form of such a fuel system, the fuel is pressurized by an electronic or mechanical pumping assembly into a common rail and distributed to electromagnetic nozzles, which inject pressurized fuel into the engine cylinders. Both the electronic pump and the electromagnetic nozzles are controlled by the ECM signal.

One problem with using a common rail results from the high pressures experienced in diesel engines, which are in the neighborhood of 20,000 psi. Another problem in conventional fuel injection systems is achieving a controlled duration and cut-off of the fuel injection pressure. Standard fuel injection systems commonly have an injection pressure versus time curve in which the pressure increases to a maximum and then decreases, following a somewhat skewed, triangularly-shaped curve. Such pressure versus time relationship initially delivers a relatively poor, atomized fuel penetration into the engine cylinder because of the low injection pressure. When the pressure curve reaches a certain level, the pressure provides good atomization and good penetration. As the pressure is reduced from its peak pressure, the decreasing pressure again provides poor atomization and penetration, and the engine discharges high emissions of particulates and smoke.

One of the objects of fuel injection designers is to reduce unburned fuel by providing a pressure versus time curve having a square configuration, with an initially high pressure increase to an optimum pressure, providing good atomization, and a final sharp drop to reduce the duration of poor atomization and poor penetration.

Examples of some prior art fuel injection nozzles may be found in U.S. Pat. No. 4,527,737 which issued July 9, 1985 to John I. Deckard; U.S. Pat. No. 4,550,875 which issued Nov. 5, 1985 to Richard F. Teerman, Russell H. Bosch, and Ricky C. Wirth; U.S. Pat. No. 4,603,671 which issued Aug. 5, 1986 to Turo Yoshinaga, et al.; U.S. Pat. No. 3,331,327 which issued to Vernon E.

Roosa n Jul. 18, 1967; and U.S. Pat. No. 4,509,691 which issued Apr. 9, 1985 to Robert T. J. Skinner. An example of a high pressure common rail of the prior art may be found in U.S. Pat. No. 4,777,921, which issued Oct. 18, 1988, to Miyaki et al. Literature pertaining to electromagnetic fuel injection pumps may be found in Paper No. 880421 of the SAE Technical Paper Series entitled "EMI - Series - Electromagnetic Fuel Injection Pumps" discussed at the Feb. 29-Mar. 4, 1988 International Congress & Exposition at Detroit, Mich. Other literature pertaining to the subject include: SAE Technical Paper Series No. 840273 discussed Feb. 27-Mar. 2, 1984 at the International Congress & Exposition, Detroit, Mich.; SAE Technical Paper Series 850453 entitled "An Electronic Fuel Injection System for Diesel Engines" by P. E. Glikin discussed at the International Congress & Exposition at Detroit, Mich. on Feb. 25, 1985; SAE Technical Papers Series 810258 by R. K. Cross, P. Lacra, C. G. O'Neill entitled "Electronic Fuel Injection Equipment for Controlled Combustion in Diesel Engines," dated Feb. 23, 1981; SAE Technical Paper Series 861098 entitled "EEC IV—Full Authority Diesel Fuel Injection Control" by William Weseloh presented Aug. 4, 1986; and, United Kingdom Patent Application No. GB-2118624A filed Mar. 3, 1983 by Henry Edwin Woodward.

SUMMARY OF THE INVENTION

The broad purpose of the present invention is to provide an improved high pressure common rail fuel injection system. In the preferred embodiment, the system employs a novel electromagnetic injector having a needle valve with an inner end attached to a spring cage, which is pressure assisted at the closing and slowed down at the opening by residual pressure maintained in a balancing chamber within the spring cage.

Fuel is delivered to the injector by a solenoid-actuated valve. The high pressure fuel biases the needle valve to an open position. When the injector solenoid is de-energized, the solenoid valve stops fuel pressure access to the needle and the pressure drops in the nozzle due to nozzle bleeding into the engine's combustion chamber. At the end of injection, a portion of the high-pressure fuel is bypassed to the balancing chamber to assist the spring and urge the needle valve towards its closed position.

The pressure assistance to needle valve closure is adjustable by sizing the orifice between the upper and lower chambers of the spring cage to restrict the fuel through the orifice to the required pressure for assistance. A sized orifice in the lower balancing chamber will assist the needle opening at the next injection slowing it down to the engines requirements.

The system of the invention employs a novel multi-element fuel pump. Four pumping elements are mounted about a camshaft having a pair of lobes disposed at 180 degrees apart. When the camshaft turns 90 degrees, it moves a first pair of opposed pumping means in a delivery motion, and the other two pumping means are in a suction motion. As the camshaft continues its rotation, the two pair of pumping elements alternate in delivering fuel toward the corresponding solenoid valve assemblies. In one embodiment, the pump is actuated by two solenoid valve assemblies in response to an electrical signal from an electronic control module. In another embodiment, the pumping elements are mechanically actuated.

Two forms of common rail are disclosed. In both forms, the common rail has a one-piece metal housing having a rectangular shape. Fuel is delivered from the pump in one direction into the common rail and discharged at right angles to the injectors. One form of common rail is applied to the engines having cylinders arranged in "V" configuration and has a central chamber where the fuel enters, and two side chambers where the fuel exits to the electromagnetic injectors. The central chamber is connected to the side chambers through cross-drilled holes. This will help to eliminate the pressure fluctuations in the central passage of the rail caused by the pumping strokes and reflected waves, and have a constant pressure and fuel distribution in the side chambers. In diesel engines having the cylinders disposed in an "in line" configuration, the common rail has a central chamber and a side chamber, connected with cross-drilled holes.

The pressure in the common rail is monitored by the electronic control module through a pressure sensor mounted on the common rail. The electronic control module will maintain the required pressure in the rail by adjusting accordingly the signal to the solenoid valve assemblies.

One embodiment of the present invention is a high pressure common rail for use in a diesel fuel injection system comprising a body having a longitudinal central chamber adapted to receive fuel under pressure and one or more side chambers adapted to discharge fuel under pressure, and cross-drilled passage means connecting the central chamber with the side chambers to eliminate the pumping stroke effect and the wave reflection effect in fuel entering the central chamber under pressure and to thereby provide a constant pressure and fuel distribution in pressurized fuel discharged from the side chambers.

Another embodiment of the present invention is a fuel pump for a diesel engine fuel injection means comprising a body adapted to receive fuel from a source, a rotatable camshaft supported in the body so as to be rotatable about an axis, and having a pair of cam lobes including a first cam lobe and a second cam lobe disposed 180 degrees apart and adapted to rotate in an annular path about the axis of rotation of the camshaft, at least one pair of reciprocating pumping elements mounted in the body perpendicular to the axis of rotation of the camshaft, each of the pumping elements including an elongated plunger having an axial passage, including a first end and a second end, the first end being connected to a source of liquid fuel, a structure slideably mounted on the plunger so as to form an expandable chamber at the second end of the axial passage, and being movable either to enlarge or reduce the volume of the chamber depending upon the direction of relative motion of the structure and the plunger, tappet means connecting the camshaft to the structure such that as the chamber is being enlarged in volume, fuel is received therein, and as the chamber is being reduced in volume, fuel is discharged therefrom, and means for fluidly connecting the pumping elements to fuel injection means for passing fuel under pressure thereto in response to rotation of the camshaft.

Another embodiment of the present invention is an electromagnetic injection injector for supplying fuel to an internal combustion engine comprising an injector body having an upper portion and a lower portion, and having an internal passage means with a first end in the upper portion for receiving pressurized fuel and a sec-

ond end in the lower portion for passing pressurized fuel from the passage, a solenoid-actuated first valve slideably mounted at the first end of the passage means having a pressure balanced annulus operable between a solenoid-energized position in which high pressure fuel is delivered through the annulus to the passage means, and a solenoid de-energized position in which high pressure fuel is blocked by the annulus from passing to the passage means; a needle valve movable in the body to control the flow of pressurized fuel through the second end of the passage means, the needle valve being movable in a first direction toward an open position for passing pressurized fuel through the second end of the passage means when the solenoid-actuated valve is in the solenoid-energized position, and an opposite, second direction toward a closed position for blocking pressurized fuel from passing through the second end of the passage means when the solenoid-actuated valve is in the solenoid de-energized position, a spring cage forming a seat for the needle valve in the body adjacent the second end of the passage in fluid communication with the passage means, biasing the needle valve in the second direction, and having an upper balancing chamber and a lower balancing chamber, and a first sized orifice therebetween, and an adjustable pressure balanced second valve slideably mounted on the lower portion of the body and having means operable to communicate pressurized fuel into the spring cage to further bias the needle valve in the second direction to a closed position when the solenoid-actuated valve is in the solenoid de-energized position to thereby obtain a sharp end of injection, and a second sized orifice in the lower balancing chamber in fluid communication with means to maintain a residual fuel pressure within the spring cage when the solenoid-actuating valve is in the solenoid de-energized position to thereby slow the movement of the needle valve in the first direction toward an open position when the solenoid-actuated valve is next in the solenoid-energized position.

Another embodiment of the invention is a high pressure, common rail, fuel injection system for injecting metered amounts of highly pressurized fuel into the cylinder of a diesel engine comprising a first body adapted to receive fuel from a source, a rotatable camshaft supported in the first body so as to be rotatable about an axis, and having a pair of cam lobes including a first cam lobe and a second cam lobe disposed 180 degrees apart and adapted to rotate in an annular path about the axis of rotation of the camshaft, at least one pair of reciprocating pumping elements mounted in the first body perpendicular to the axis of rotation of the camshaft, each of the pumping elements including an elongated plunger having an axial passage, including a first end and a second end, the first end being connected to a source of liquid fuel, a structure slideably mounted on the plunger so as to form an expandable chamber at the second end of the axial passage, and being movable either to enlarge or reduce the volume of the chamber depending upon the direction of relative motion of the structure and the plunger, tappet means connecting the camshaft to the structure such that as the chamber is being enlarged in volume, fuel is received therein, and as the chamber is being reduced in volume, fuel is discharged therefrom, means for fluidly connecting the pumping elements to common rail means for passing fuel under pressure thereto in response to rotation of the camshaft, the common rail means including a second body having a longitudinal central chamber adapted to

receive fuel under pressure from the first body and one or more side chambers adapted to discharge fuel under pressure, cross-drilled passage means connecting the central chamber with the side chambers to eliminate the pumping stroke effect and the wave reflection effect in fuel under pressure and to provide a constant pressure and fuel distribution in fuel discharged from the side chambers, means for fluidly connecting the common rail means to fuel injection means for passing fuel under pressure thereto in response to rotation of the camshaft, the fuel injection means including an injector body having an upper portion and a lower portion, and having an internal passage means with a first end in the upper portion for receiving pressurized fuel and a second end in the lower portion for passing pressurized fuel from the passage, a solenoid-actuated first valve slideably mounted at the first end of the passage means having a pressure balanced annulus openable between a solenoid-energized position in which high pressure fuel is delivered through the annulus to the passage means, and a solenoid de-energized position in which high pressure fuel is blocked by the annulus from passing to the passage means, a needle valve movable in the injector body to control the flow of pressurized fuel through the second end of the passage means, the needle valve being movable in a first direction toward an open position for passing pressurized fuel through the second end of the passage means when the solenoid-actuated valve is in the solenoid-energized position, and an opposite, second direction toward a closed position for blocking pressurized fuel from passing through the second end of the passage means when the solenoid-actuated valve is in the solenoid de-energized position, a spring cage forming a seat for the needle valve in the injector body adjacent the second end of the passage and biasing the needle valve in the second direction in fluid communication with the passage means, and having an upper balancing chamber and a lower balancing chamber, and a first sized orifice therebetween, and an adjustable pressure balanced second valve slideably mounted on the lower portion of the injector body and having means openable to open the second valve when the solenoid-actuated valve is in the solenoid de-energized position to communicate pressurized fuel into the spring cage to aid the spring cage in biasing the needle valve in the second direction to a closed position to thereby obtain a sharp end of injection, and a second sized orifice in the lower balancing chamber in fluid communication with means to maintain a residual fuel pressure within the spring cage when the solenoid-actuating valve is in the solenoid de-energized position to thereby slow the movement of the needle valve in the first direction toward an open position when the solenoid-actuated valve is next in the solenoid-energized position.

Still further objects and advantages of the invention will become readily apparent to those skilled in the art to which the invention pertains upon reference to the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a high pressure common rail fuel injection system, illustrating the preferred embodiment of the invention.

FIG. 2 illustrates a high pressure, common rail fuel injection system with a mechanical pump assembly.

FIG. 3 is a view of an electronically-actuated pump assembly illustrating the preferred fuel pump.

FIG. 4 is a view of a preferred solenoid valve assembly.

FIG. 5 is a sectional view as seen along lines marked FIG. 5—FIG. 5 in FIG. 4.

FIG. 5A is an enlarged fragmentary view of the solenoid valve in closed position for delivering fuel to the common rail.

FIG. 5B is an enlarged fragmentary view showing the solenoid valve in open position disposed for bypassing the fuel.

FIG. 6 is a side view of the preferred common rail of FIG. 1.

FIG. 6A is a cross-sectional view of preferred common rail with one central passage and two side passages.

FIG. 6B is a cross-sectional view of a common rail with one central passage and one side passage.

FIG. 7 is a longitudinal sectional view of a preferred electromagnetic injector.

FIGS. 7A and 7B are an enlarged sectional views showing the inlet opening and closing of the injection fuel delivery passage by the injectors solenoid valve.

FIGS. 7C and 7D are views of the opening and closing of the fuel passage to the balancing chamber.

FIG. 7E is an enlarged view along lines 7E—7E of FIG. 7.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, such alterations and further modifications in the illustrated devices, and such further applications of the principles of the invention as illustrated therein being contemplated as would normally occur to one skilled in the art to which the invention relates.

Referring now to the drawings, a preferred fuel injection system 10 comprises an electronic controlled pump means 12, solenoid valve assembly means 14A and 14B, a common rail assembly 16 and electromagnetic injector means 18. Fuel is delivered from a fuel supply 20 through conduit means 22 to solenoid valve assembly means 14A and 14B. The two valve assembly means 14A and 14B are identical in construction, their function differing according to their fluid connection with pump means 12.

Referring now to FIG. 4, solenoid valve means 14A comprises a body 28 having a longitudinal passage 30 including halves 30A and 30B. A transverse passage 32 extends at right angles to passage 30 and intersects passage 30. One end of passage 32 is enlarged at 34. A fuel inlet fitting 36 is mounted in enlarged passage 34. A pair of fasteners 38 and 40 fasten fitting 36 to the body 28. Fitting 36 has a passage 42 for receiving fuel from conduit means 22A (FIG. 1).

Referring now to FIGS. 4, 5A and 5B, an electromagnetically operated solenoid 44 is mounted on the body 28 and is operatively connected to control valve 46, which is slideably disposed in passage 32 for reciprocatory motion. Valve 46 has an annular groove 48, spaced from the outer end of the valve. The bottom of the enlarged end of the bore 34 is tapered at 50 to provide a seat for outer end 52 of control valve 46.

Solenoid 44 is operated to move the control valve 46 between a closed position (FIG. 5A) in which valve end

52 engages seat 50 to block fluid flow between passages 42 and 32, and an open position (FIG. 5B) in which the control valve 46 abuts fitting 36 to open fluid flow between passage 32 and a pair of passages 52A and 52B in fitting 36 to passage 42. In both positions, there is a fluid connection between the halves 30A and 30B of passage 30.

Referring now to FIG. 4, body 28 has an internal passage 56 forming an extension of passage 30A. The body has a second passage 58 at right angle to and intersecting passage 56. A fitting 60 is mounted on the body 28 and has an internal passage 62 forming an extension of one end of passage 58. A second fitting 64 is mounted on the opposite side and has an internal passage 66 forming an extension of the end of passage 58.

Referring now to FIG. 1, conduit 68 forms a fluid connection between fitting 60 and pump means 12, and another conduit 70 forms a fluid connection between fitting 64 and a pump means 12.

Returning now to FIGS. 1, 4, and 5, a nut 72 is mounted on the opposite end of the body 28. Nut 72 has an internal chamber 74. A threaded fitting 76 is mounted on nut 72. Fitting 76 has a passage 78 connected to a conduit 80 (FIG. 1). A cup-shaped member 82 is mounted in chamber 74. Member 82 has a cylindrical internal wall, and an opening 84 communicating with passage 30B, which forms a valve seat 85 for slideably mounted, hollow check valve 86. Check valve 86 has a conical end 88, which mates with valve seat 85 to close fluid flow from passage 30 into chamber 74. A spring bias member 90 is mounted in the check valve 86 and biases check valve 86 toward its closed position.

Referring now to FIG. 5, check valve 86 has a square cross-section slideably mounted in the cylindrical internal wall member 82 to permit fuel flow from passage 30 into chamber 74 when conical end 88 is spaced from the valve seat 85.

Still referring to FIGS. 1 and 4, when solenoid means 44 is electrically energized, it retracts control valve 46 away from fitting 36 to close fluid flow between passage 32 and passage 42. The control valve 46 has an annular shoulder 94. A washer 96 is mounted on the shoulder. A return spring 98 is disposed between the washer 96 and a retainer 100 to bias the control valve 46 toward fitting 36 and the control valve's open position.

In operation, when the control valve 46 is seated in its closed position, fluid flow is blocked between passage 30 and conduit 22A (FIG. 1). When check valve 86 is opened, fuel passes from the pumping means through passages 30A and 30B and out to conduit 80 (FIG. 1). When the control valve 46 is raised to engage fitting 36 in the valve's open position, the fuel passes from passage 30A and out conduit 22A, when check valve 86 is closed.

Referring now to FIG. 1, the second solenoid assembly 14B is identical in construction to solenoid 14A and includes a solenoid 110 mounted on a body 112. A nut 114 is mounted on one end of the body and has an internal passage 116. One end of passage 116 is connected by fitting 118 and conduit 120 to the pump means 12. The opposite end of internal passage 116 is connected by fitting 122 and conduit 124 to the pump means 12 in a manner which will be described.

The body 112 has an internal passage means 126, one end of which is connected to internal passage 116 and the other end of which terminates with fitting 128. A check valve 130 provides means for opening and closing fuel flow from the body 112 to a conduit 132, which

is connected to common rail 16. Fuel is received from fuel supply 20 through a conduit 134.

Solenoid 110 moves control valve 111 to control fluid flow between internal passage means 116 and conduit 134 in the manner that control valve 46 controls flow between passage 30 and conduit 22A. Fuel is discharged from conduits 80 and 132 to common rail 16.

Referring now to FIG. 1, 6 and 6A, common rail 16 has a relatively flat metal body 150. Body 150 has a central chamber 152B and side chambers 152A and 152C. Body 150 has a rectangular cross-section bounded by end walls 154 and 156, and side walls 158 and 160. End walls 154 and 156 have a pair of inlet fittings 162 and 164. Inlet fitting 162 is connected to conduit 80 for receiving fuel from solenoid valve assembly 14A into the common rail central chamber 152B. Fitting 164 is adapted to receive fuel from the solenoid valve assembly 14B through conduit 132 into the central chamber 152B. Side wall 158 has fuel discharge fittings 166A through 166F. The opposite side wall 160 has fuel discharge fittings 168A through 168F.

The side chambers 152A and 152C communicate with central chamber 152B through cross-drilled holes 165A through 165F. The cross-drilled holes 165A through 165F create a constant pressure and a perfect pressure distribution in the side chambers and eliminate the pressure fluctuations which occur in the central passage because of the pumping strokes and reflected pressure waves.

The number of fuel discharge fittings 165, 166, 168, or the number of cross-drilled holes can vary depending on the engine application. For example, for a six cylinder engine, the common rail 16 will have only twelve discharge fittings and six cross-drilled holes (for an arrangement like that illustrated in FIG. 6A) or six fittings and six cross-drilled holes (for an arrangement like that illustrated in FIG. 6B).

Each of the fuel discharge fittings 166A through 166F, and 168A through 168F is connected by a conduit, such as conduit 170, to an electromagnetic injector typified by injector means 18.

End wall 154 has an outlet 172. A fitting 174 is mounted in the outlet opening and connected by a conduit 176 to an adjustable relief valve 178. The adjustable relief valve 178 is adapted to protect and relieve the pressure in chamber 152A when it exceeds a maximum predetermined pressure level.

A pressure transducer 180 is also mounted in the end wall 154, and is connected to the Electronic Control Module 440, monitoring the pressure in chamber 152C.

Referring now to FIGS. 1 and 3, fuel pump means 12 comprises a housing 200. A camshaft 202 is mounted in the housing and is connected by mechanical connection 204 to the engine 206. The camshaft 202 has two identical lobes 208 and 210 mounted 180 degrees apart. Four identically constructed pumping means 212, 214, 216, and 218 are mounted in the housing, spaced 90 degrees with respect to one another about the axis of rotation of the camshaft. Pumping means 212 is typical of the four and includes a mounting flange 220 disposed in an opening 222 in the pump housing 200. The flange 220 carries a cylindrical skirt 224 and supports a fitting 228 having an internal passage 230.

A tappet bushing 240 is mounted in the skirt 224. A retainer ring 242 is carried by the bushing 240 and is slideably mounted on the inner surface of skirt 224.

A tappet roller 244 is rotatably mounted on a pin 246 carried by the bushing 240. The roller 244 is rotatably

engaged with the camshaft 202 such that the tappet bushing 240 is movable within the skirt 224 depending upon the position of the camshaft 202.

The bushing 240 has an internal bore 250. A plunger 252 is slideably mounted within the bore 250 to form a pumping chamber 256, which expands and contracts depending upon the position of the tappet roller 244 on the camshaft 202. The plunger 252 has an internal passage 260 for passing fuel toward or away from pumping chamber 256. The arrangement is such that as the tappet roller 244 rides up on either camshaft lobe 208 or lobe 210, the bushing 240 moves toward the plunger 252 to reduce the size of pumping chamber 256, thereby delivering fuel under pressure through passage 230. As the camshaft 202 is rotated so the tappet roller 244 is riding on the back side of either camshaft lobe, a spring bias member 270 having one end engaged with the plunger 252 and its other end engaged with the bushing 240, urges the bushing toward the camshaft 202 to enlarge chamber 256. As pumping chamber 256 is enlarged, the chamber creates a low pressure area, drawing fuel into the chamber through the passage 260 in the plunger 252.

Thus, it can be seen that as the camshaft 202 is rotated, it simultaneously pumps fuel out of the pumping chambers of pumping means 214 and 218, while drawing fuel into the pumping chambers of pumping means 212 and 216. As the camshaft 202 continues its rotation, the fuel is drawn into the pumping chambers of pumping means 214 and 218, and pumped out of the pumping chambers of pumping means 212 and 216. This provides a pumping action having a balanced motion of the pumping components and eliminating the bending stresses on the camshaft 202.

Referring now to FIG. 1, pumping means 212 and 216 are connected by conduits 124 and 120, respectively, to solenoid assembly 14B. Similarly, pumping means 214 and 218 are connected by conduits 70 and 68, respectively, to solenoid assembly 14A. The pumping means 212, 216, 214 and 218 either pump fuel toward the common rail 16 or recirculate fuel to the fuel supply conduits depending upon whether the control valves 46 and 111 in the solenoid valve assemblies 44 and 110 are open or closed.

The solenoids on the solenoid valve assemblies 44 and 110 are energized or de-energized and are controlled by the Electronic Control Module 440, which is monitoring the pressure in the common rail 16 through pressure transducer 180. This way, the pressure in the common rail 16 can be preset for every engine speed by setting the right parameters for the Electronic Control Module.

Referring now to FIGS. 7, 7A, 7B, 7C, 7D and 7E, a typical electromagnetic injector 18 comprises a body 300 having a nut 302 threadably mounted at its upper end, and a retaining cap 304 mounted at its lower end. An electromagnetically actuated solenoid 306 is mounted on the nut 302. The solenoid 306 has an armature 308 disposed in a chamber 310 and is sealed to nut 302 by means of an "O" ring 312.

The armature 308 of the solenoid 306 is connected to an elongated valve 314, which extends through a chamber 316 in the nut. Valve 314 is slideably mounted in bore 318 in the body 300. The valve has a longitudinal internal passage 320 and a cross passage 322 has its ends communicating with chamber 316 (FIG. 7E), which in turn communicates with passage 324 in fitting 326.

Referring now to FIGS. 7A and 7B, valve 314 has an annular groove 328. An annular retaining plate 330 is

mounted in the groove and has a thickness less than the width of the groove. Shims 332 are mounted adjacent the retaining plate.

The retaining plate thickness is used to adjust the travel of the valve 314 by allowing the valve to move only as far as the ends of the groove and the retaining plate thickness allows. FIG. 7A illustrates the valve 314 in its lowest position in abutment with retaining plate 330, while FIG. 7B shows the valve in its upper position in abutment with the lower edge of retaining plate 330.

Valve 314 has an annular shoulder 334 disposed in chamber 316. A return spring 336 (FIG. 7) is mounted in the chamber with one end in abutment with nut 302, and the other end in abutment with spring seat 335, seating on shoulder 334 to bias valve 314 toward the retaining cap 304.

The valve 314 has an annular passage 340 adjacent its lower end. The body 300 has an internal passage 342 in communication with passage 340. A threaded fitting 344 is mounted on the body 300 with an inlet passage 36 in communication with passage 342. Passage 342 is connected through conduit 170 (FIG. 1) for receiving fuel from the common rail 16.

The body 300 also has a delivery passage 348 with an inlet opening 350 terminating at bore 318. The location of opening 350 is such that when valve 314 is in its lowermost position, the valve blocks fluid through opening 350. When the valve 314 is in its upper position, it opens a fluid connection between annular passage 340 and inlet opening 350.

Referring now to FIG. 7, the body 300 also has a passage 360 and with passage 361 and 363 connects the bottom of the body 300 to bore 318. A small chamber 362 is defined between the lower, extreme end of the valve 314 and the bottom of bore 318 to provide room for the valve motion and for fluid communicating between passage 320 and chamber 370 through passages 360, 361 and 363.

Retaining cap 304 has a large internal chamber 370. Chamber 370 has a bottom opening 372. An elongated spray tip 374 is disposed in the chamber 370 with its lower end extending through opening 372. The outer end of the spray tip has opening means 376 for passing fuel to the engine cylinder (not shown).

The spray tip 374 has an elongated, slightly tapered passage 378. The lower end of the passage 378 passes fuel to opening means 376. The upper end of passage 378 is enlarged at 380 and is fluidly connected to a passage 382 in the spray tip 374. Enlarged section 380 is tapered and terminates with a cylindrical bore 384, which extends through the upper end of the spray tip 374.

A needle valve 386 is mounted in passage 378. The lower end of the needle valve 386 is tapered at 390 to seat against a tapered seat 392 in the spray tip 374 for opening or closing fuel flow through passage means 376. The upper end of the needle valve 386 has a narrowed end 394. A spring seat 396 has a bore 398 receiving the narrowed end 394 of the needle valve 386. Spring seat 396 is movable in chamber 406 to define the travel of the needle valve 386 between its open and closed positions. The spring seat 396 has a raised mid-section 400 to limit the needle valve travel.

Referring now to FIGS. 7, 7C and 7D, spring cage 402 is mounted in chamber 370. The cage 402 has wall 404 separating a lower balancing chamber 406, and an upper balancing chamber 408. A coil spring 410 in the lower chamber has its upper end engaging wall 404, and

its lower end engaging spring seat 396 to urge spring seat 396 and the needle valve 386 toward the needle valve's closed position. A coil spring 412 in the upper chamber has its lower end engaged with wall 404. A valve 414 is mounted in the upper chamber and engages the upper end of spring 412. Valve 414 has an annular section 418 and a tapered portion 416 seating on seat 417 of injector body 300. The upper portion of valve 414, is engaging bore 450 in body 300 and has an inside threaded portion 452.

A piston-screw 420 is engaging valve 414 through a threaded portion 419, on the lower end, and has a securing nut 422 which secures its adjusted height to valve 414. The piston-screw 420 is adjusted such that it maintains a preset clearance 423 to the lower end of valve 314 when the valve is lifted to its upper position by energizing the solenoid 306. When solenoid 306 is de-energized, valve 314 is lowered by spring 336 and pushes downwards piston-screw 420 and valve 414 unseating valve seat 416 from seat 417 allowing fuel from passage 430 and 421 to enter chamber 408 and chamber 406, through orifice 424.

Spring cage 402 has a passage 430 communicating on the upper end with passage 348, and on the lower end with passage 382 from spray tip 374. The spring cage 402 also has a lateral orifice 440, which extends from lower chamber 406 to outside spring cage 402, communicating with chamber 370 along the inside wall of retainer cap 304.

Referring now to FIG. 1, during engine operation, the fuel from supply 20, such as a fuel tank, is delivered at a predetermined pressure by a supply pump (not shown) to an electronically controlled pump means 12 through solenoid valve assembly means 14A and 14B. Each opposed pair of pumping means 212, 214, 216 and 218 of the pump means 12 draw the fuel into their pumping chambers as the camshaft 202 is turned, and then pump the fuel back to the corresponding solenoid valve assembly 14A or 14B.

The fuel from the pumping elements 212, 214, 216 and 218 passes through the solenoid valve assemblies 14A and 14B and is recycled to the fuel supply 20 depending upon the position of the solenoid control valves 46 and 111. For example, when the solenoid valve assembly 14A is energized by a signal with a certain pulse coming from the Electronic Control Module 440, the solenoid armature 45 (FIG. 4) pulls the control valve 46 to its closed position, and the fuel coming from the pumping elements through passage 30 opens check valve 86 (FIG. 4) to pass fuel through fitting 76 toward the common rail 16.

The two solenoid valve assemblies 14A and 14B are alternatively energized, having been correlated to the timing of the opposed pumping elements.

The pumping process ends when the solenoids of the solenoid valve assemblies 14A and 14B are de-energized, and, for example, the control valve 46 forced by springs 98 opens tapered seat 50 and allows fuel passing 30A to pass into passage 42 and return to fuel tank, causing a pressure drop in passage 30B, which will cause spring 90 to seat valve 86, disconnecting the fuel flow from the pump to the common rail.

The fuel coming from the solenoid valve assemblies enters into the common rail central passage 152B through either fitting 162 or 164, depending upon which solenoid valve assembly is in the pumping mode. The fuel is accumulated in the common rail at a predetermined pressure adjusted according to Electronic Con-

trol Module 440 commands. The Electronic Control Module 440 monitors the common rail pressure with a Pressure transducer 180 and according to the its preset input data, will adjust the signal to the solenoid valve assemblies to achieve the necessary common rail pressure.

The high pressure fuel from the common rail's central passage passes through cross-drilled passages 165A through 165F into side passages 152A and 152C. The cross-drilled orifices will restrict the pumping stroke effect and fuel wave reflects and the side passages will have a constant high pressure all along the side passages, insuring an equal fuel and pressure distribution to all electromagnetic injectors through their corresponding outlet fitting. This common rail construction illustrated in FIG. 6A is used on diesel engines having their cylinders arranged in "V" configuration. The number of cross-drilled passages is equal to half of the number of the side fuel exit fittings.

FIG. 6B illustrates a common rail with one central passage 504B and only one side passage 504A, used for diesel engines having an "in line" cylinder arrangement. The fuel enters the rail through fittings 508 and 518 mounted on the opposite sides of the central passage 504B. The side passage 504A has a pressure transducer 506 mounted at one end and relief valve 516 mounted at the other end. The number of cross-drilled passages 512A through 512F is equal to the number of side fuel exit fittings.

The number of common rail fuel exit fittings can change according to the number of diesel engine cylinders were this system is applied.

The fuel from the common rail is delivered to each of the electromagnetic injectors, entering the injector body through fitting 344. The fuel flow stops at injectors solenoid valve annular passage 340 having opening 350 normally closed. When solenoid 306 is energized with a signal coming from the Electronic Control Module 440, the armature 308 and valve 314 are lifted, opening fuel flow through opening 350, passages 348, 421, 430, 382 and 378. The solenoid valve is pressure-balanced by the upper and lower sides of annular passage 340.

The pressurized fuel continues downward to the spray tip 374. The fuel pressure acts against the tapered section of the needle valve 386. The fuel pressure lifts the needle valve and permits the pressurized fuel to spray into the engine's combustion chamber through spray opening means 376.

With solenoid 306 energized and valve 314 lifted, piston 420 is adjusted such that it maintains a small gap 423 to valve 314 on its upper end allowing valve 414 to seat with its tapered seat 416 on the body's tapered seat 417, stopping fuel from entering passage 412 and annular passage 418 to enter the spring cage's upper chamber 408.

The injection process ends when solenoid 306 is de-energized, solenoid valve 314 is moved downwards by spring 336 and it closes opening 350. The fuel bleeding through spray holes 376 will cause a fuel pressure drop in chamber 378 and section 380, allowing spring 410 to seat needle valve 386 on seat 392, closing off fuel bleeding through spray holes 376 (FIG. 7).

At the same time, when solenoid valve 314 is lowered, the lower end of the solenoid valve eliminates gap 423 and pushes open valve 414, allowing pressurized fuel from passage 421 and annular section 418 to pass through to chamber 408. Pressurized fuel will continue

through a pre-sized orifice 424 into chamber 406 on the top of seat 396, helping spring 410 to close the needle valve earlier and providing a sharp end of injection. The pre-sized orifice 424 will determine how much pressure assistance will be applied on the top of the seat 396, helping to close the needle valve.

The pressure in chamber 406 is maintained to a certain level by sizing the bleeding orifice 440 on the side wall of the chamber 406. This residual pressure is necessary to slow the needle valve opening on the next injection according to the engine requirements.

FIG. 2 illustrates a mechanical pump assembly 600 using four standard plunger-operated, one-cylinder pumps 602, 604, 606 and 608, each having fuel metering and timing adjusted by the plunger's helix. The plungers are energized in pairs by a camshaft 610 having a pair of opposed cam lobes 612 and 614. The pumps alternate in pairs in delivering fuel to common rail 16 through conduits 616, 618, 620 and 622 in a manner similar to the embodiment of FIG. 1.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiment has been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected.

What is claimed is:

1. A high pressure, common rail, fuel injection system for injecting metered amounts of highly pressurized fuel into the cylinder of a diesel engine, comprising:

a first body adapted to receive fuel from a source; a rotatable camshaft supported in the first body so as to be rotatable about an axis, and having a pair of cam lobes including a first cam lobe and a second cam lobe disposed 180 degrees apart and adapted to rotate in an annular path about the axis of rotation of the camshaft;

at least one pair of reciprocating pumping elements mounted in the first body perpendicular to the axis of rotation of the camshaft, each of said pumping elements including an elongated plunger having an axial passage, including a first end and a second end, the first end being connected to a source of liquid fuel, a structure slideably mounted on the plunger so as to form an expandable chamber at the second end of the axial passage, and being movable either to enlarge or reduce the volume of the chamber depending upon the direction of relative motion of said structure and said plunger, tappet means connecting the camshaft to said structure such that as said chamber is being enlarged in volume, fuel is received therein, and as said chamber is being reduced in volume, fuel is discharged therefrom;

means for fluidly connecting the pumping elements to common rail means for passing fuel under pressure thereto in response to rotation of said camshaft;

the common rail means including a second body having a longitudinal central chamber adapted to receive fuel under pressure from said first body and one or more side chambers adapted to discharge fuel under pressure;

cross-drilled passage means connecting said central chamber with said side chambers to eliminate the pumping stroke effect and the wave reflection effect in fuel under pressure and to provide a con-

stant pressure and fuel distribution in fuel discharged from said side chambers;

means for fluidly connecting the common rail means to fuel injection means for passing fuel under pressure thereto in response to rotation of said camshaft;

the fuel injection means including an injector body having an upper portion and a lower portion, and having an internal passage means with a first end in said upper portion for receiving pressurized fuel and a second end in said lower portion for passing pressurized fuel from the passage;

a solenoid-actuated first valve slideably mounted at the first end of said passage means having a pressure balanced annulus openable between a solenoid-energized position in which high pressure fuel is delivered through said annulus to said passage means, and a solenoid de-energized position in which high pressure fuel is blocked by said annulus from passing to said passage means;

a needle valve movable in the injector body to control the flow of pressurized fuel through the second end of said passage means, said needle valve being movable in a first direction toward an open position for passing pressurized fuel through the second end of said passage means when said solenoid-actuated valve is in said solenoid-energized position, and an opposite, second direction toward a closed position for blocking pressurized fuel from passing through the second end of said passage means when said solenoid-actuated valve is in said solenoid de-energized position;

a spring cage forming a seat for said needle valve in the injector body adjacent the second end of said passage and biasing said needle valve in said second direction in fluid communication with said passage means, and having an upper balancing chamber and a lower balancing chamber, and a first sized orifice therebetween; and

an adjustable pressure balanced second valve slideably mounted on said lower portion of said injector body and having means openable to open said second valve when said solenoid-actuated valve is in said solenoid de-energized position to communicate pressurized fuel into said spring cage to aid the spring cage in biasing said needle valve in said second direction to a closed position to thereby obtain a sharp end of injection; and

a second sized orifice in said lower balancing chamber in fluid communication with means to maintain a residual fuel pressure within said spring cage when said solenoid-actuating valve is in said solenoid de-energized position to thereby slow the movement of said needle valve in said first direction toward an open position when said solenoid-actuated valve is next in said solenoid-energized position.

2. A high pressure common rail for use in a diesel fuel injection system comprising:

a body having a longitudinal central chamber adapted to receive fuel under pressure along its longitudinal axis and one or more side chambers having adaptations to discharge fuel under pressure through fuel injectors; and

cross-drilled passage means perpendicular to said longitudinal axis of said central chamber that directly connect said central chamber with said one or more side chambers and that are axially aligned

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with said adaptations in said one or more side chambers to discharge fuel under pressure to eliminate the pumping stroke effect and the wave reflection effect in fuel entering said central chamber under pressure and to thereby provide a constant pressure in and fuel distribution into said one or more side chambers in the absence of a separate fuel pressure regulator.

3. A common rail as defined in claim 2, in which each of said chambers has a rectangular shape.

4. A common rail as defined in claim 2 in which pressurized fuel is received into said central chamber from a first direction and is discharged from one or more of side chambers in a second direction that is at right angles to said first direction.

5. A common rail as defined in claim 2, in which there is a central chamber and one side chamber on either side thereof.

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6. A common rail as defined in claim 2, and further comprising pressure adjustment means mounted on said common rail for monitoring pressure within said common rail and for maintaining a desired pressure therein.

7. A common rail as defined in claim 2, in which said cross-drilled passage means includes cross-drilled orifices adjacent to every adaption of said side chambers to discharge fuel under pressure.

8. A common rail as defined in claim 7, in which there is a central chamber and one side chamber on either side thereof, and the number of cross-drilled orifices are equal to the number of adaptations in said side chamber to discharge fuel under pressure.

9. A common rail as defined in claim 7, in which there is a central chamber and two side chambers on either side thereof, and the number of cross-drilled orifices are equal to one-half the number of adaptations in said side chambers to discharge fuel under pressure.

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US005405712A

United States Patent [19][11] **Patent Number:** 5,405,712**Yoshimura et al.**[45] **Date of Patent:** Apr. 11, 1995[54] **SOLID OXIDE FUEL CELL GENERATOR**[75] **Inventors:** Takayoshi Yoshimura, Kurobe;
Masaki Sato, Funabashi; Toshio Arai,
Toyama, all of Japan[73] **Assignee:** YKK Corporation, Tokyo, Japan[21] **Appl. No.:** 97,373[22] **Filed:** Jul. 27, 1993[30] **Foreign Application Priority Data**

Aug. 13, 1992 [JP] Japan 4-216099

[51] **Int. Cl.⁶** H01M 8/10[52] **U.S. Cl.** 429/38; 429/32;

429/34; 429/35; 429/36

[58] **Field of Search** 429/38, 36, 35, 34,
429/32[56] **References Cited****U.S. PATENT DOCUMENTS**

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Primary Examiner—Prince Willis, Jr.*Assistant Examiner*—M. Nuzzolillo*Attorney, Agent, or Firm*—Finnegan, Henderson,
Farabow, Garrett & Dunner[57] **ABSTRACT**

A solid oxide fuel cell generator comprising: a plurality of cell mounting holes formed on the surface of a hollow dense substrate and having supports therein; and cell sections provided on recesses formed by the mounting holes and the supports, with adjacent cell sections being connected to each other by electrically conductive interconnections, in which a hollow longitudinal supply channel for supplying a fuel or fuel assistant gas is provided adjacent to the cell mounting holes in the substrate, the supply channel being kept at its other end in communication with a hollow section of the substrate inside the cell sections. The supply channel is preferably provided on both lateral sides of the substrate. The solid oxide fuel cell generator has a high areal efficiency of the cell generating part with respect to a substrate and a superior generating efficiency.

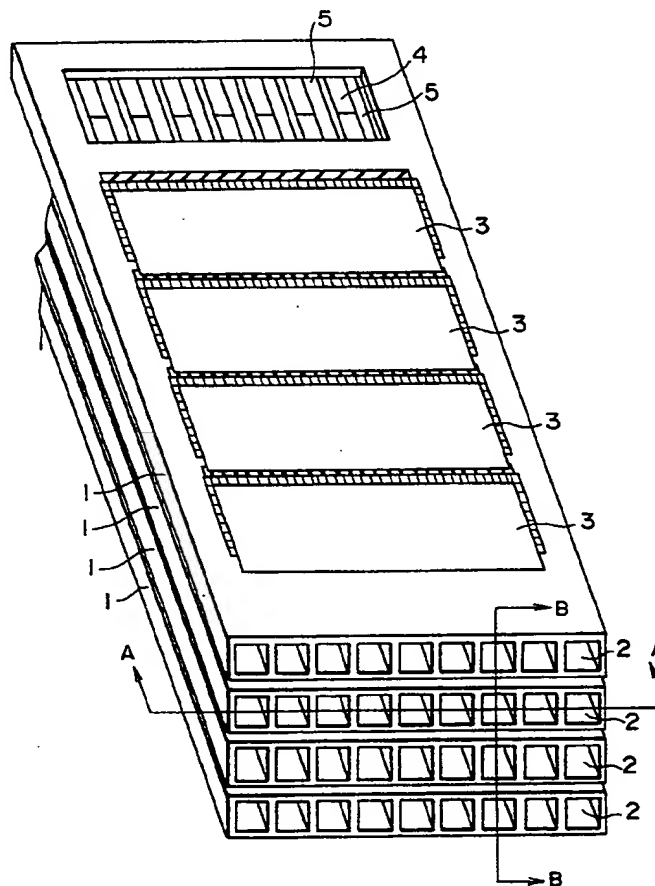
2 Claims, 13 Drawing Sheets

FIG. 1

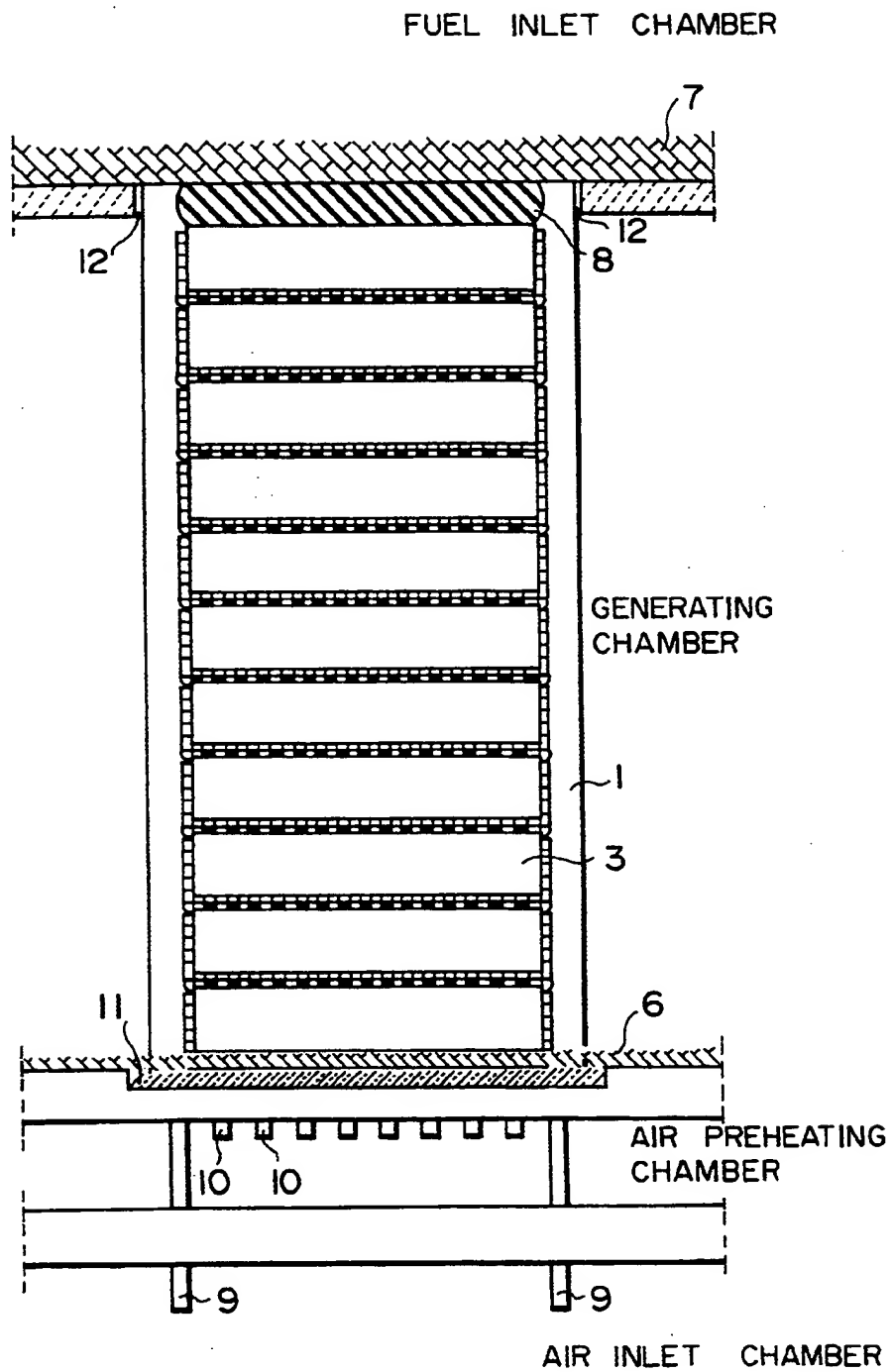


FIG. 2

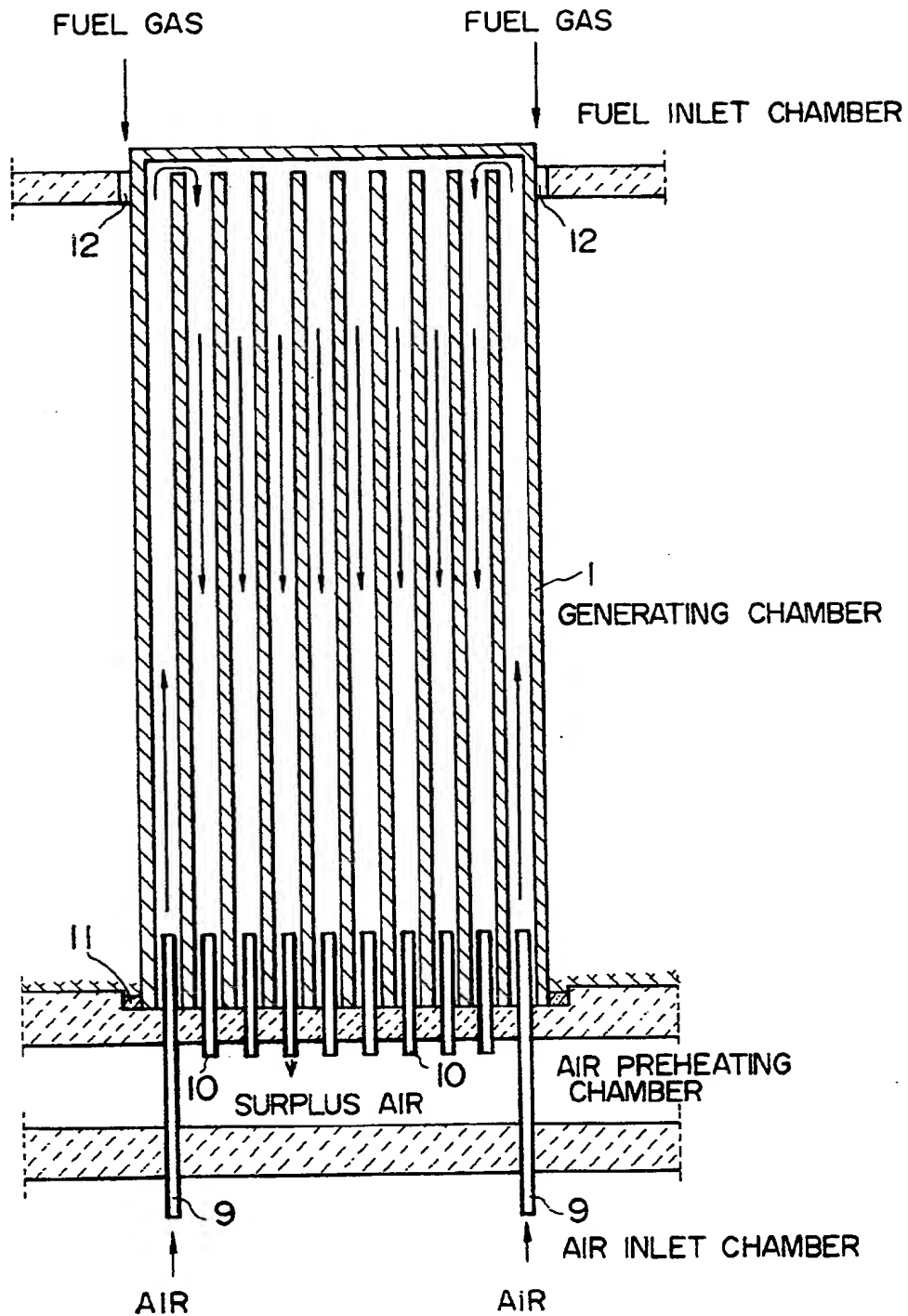


FIG. 3

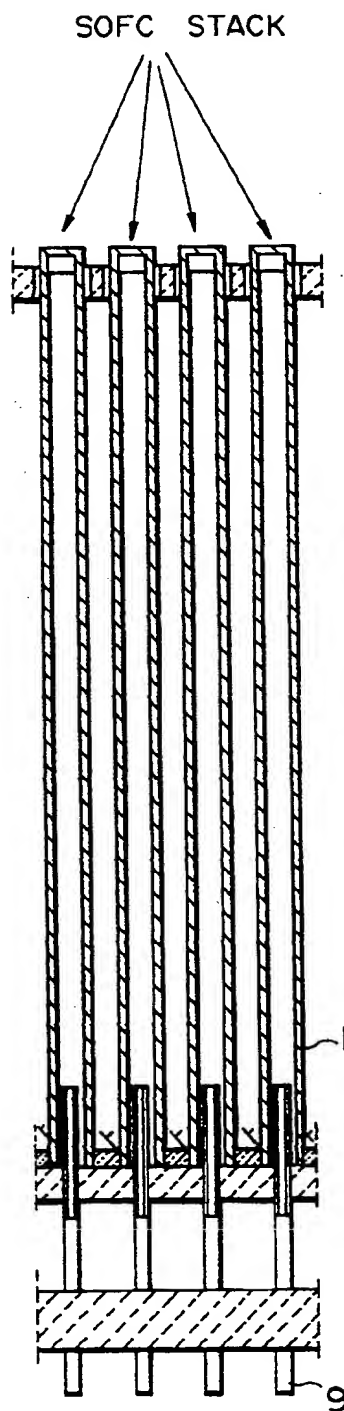


FIG. 4

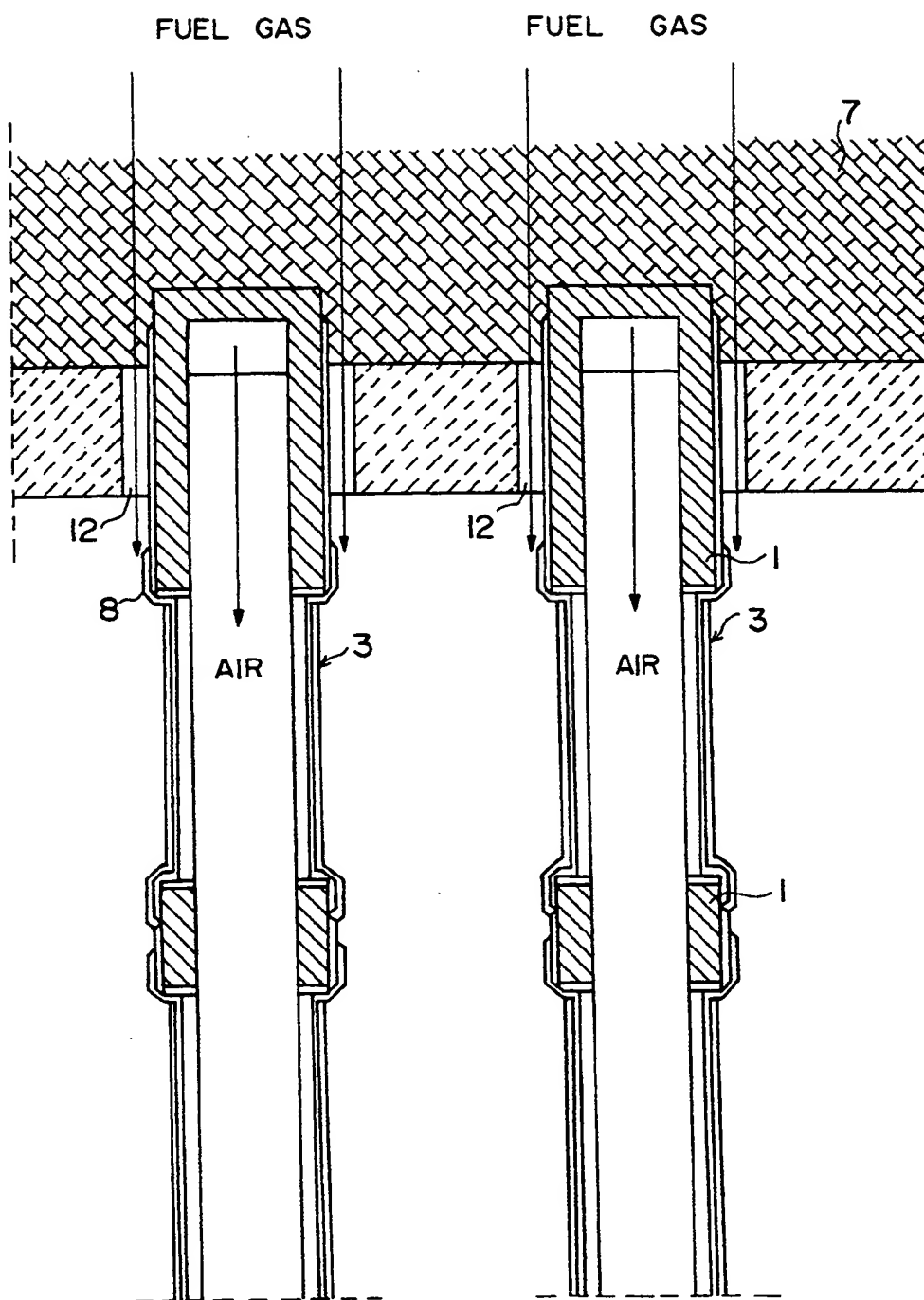


FIG. 5

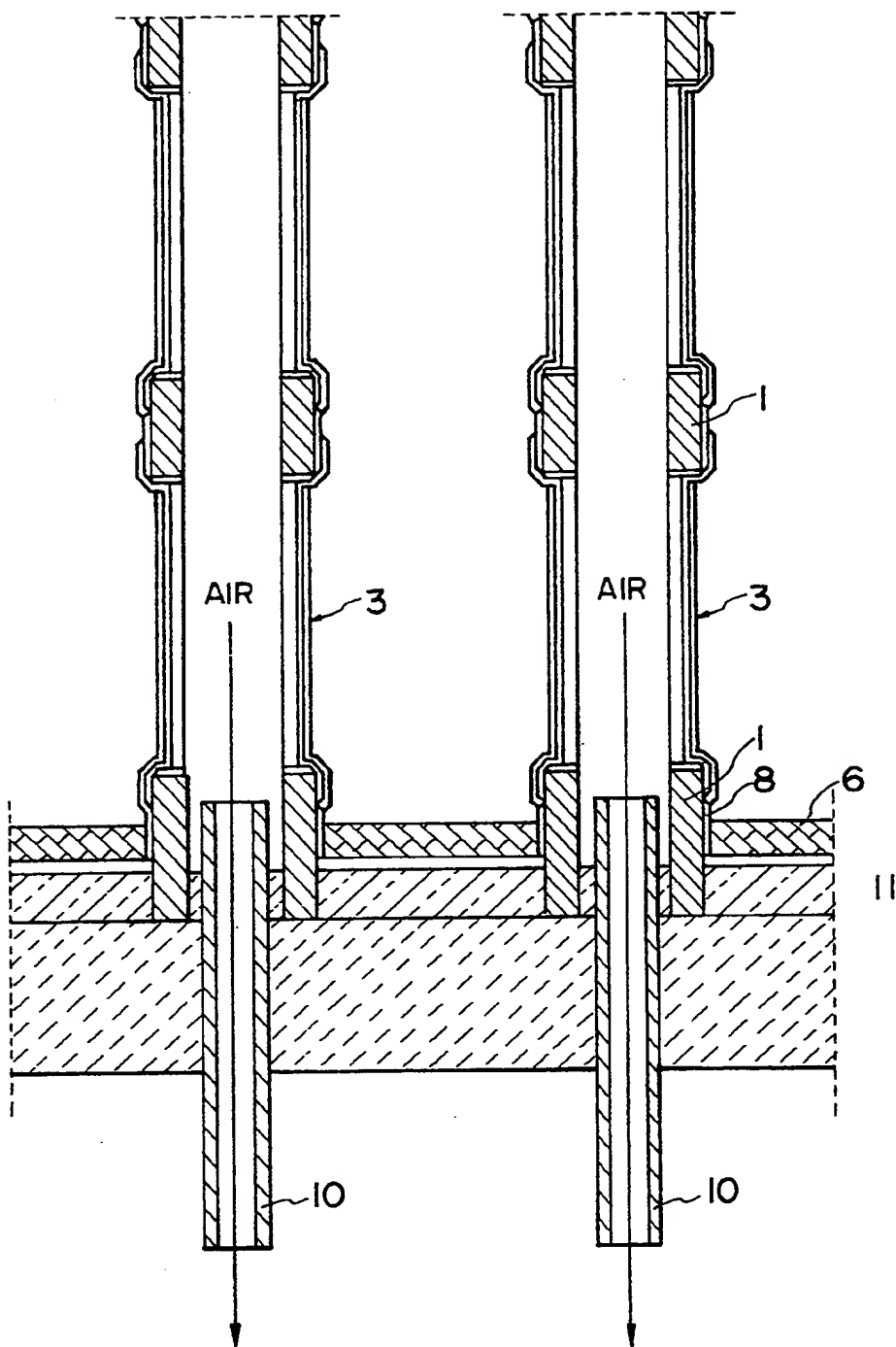


FIG. 6

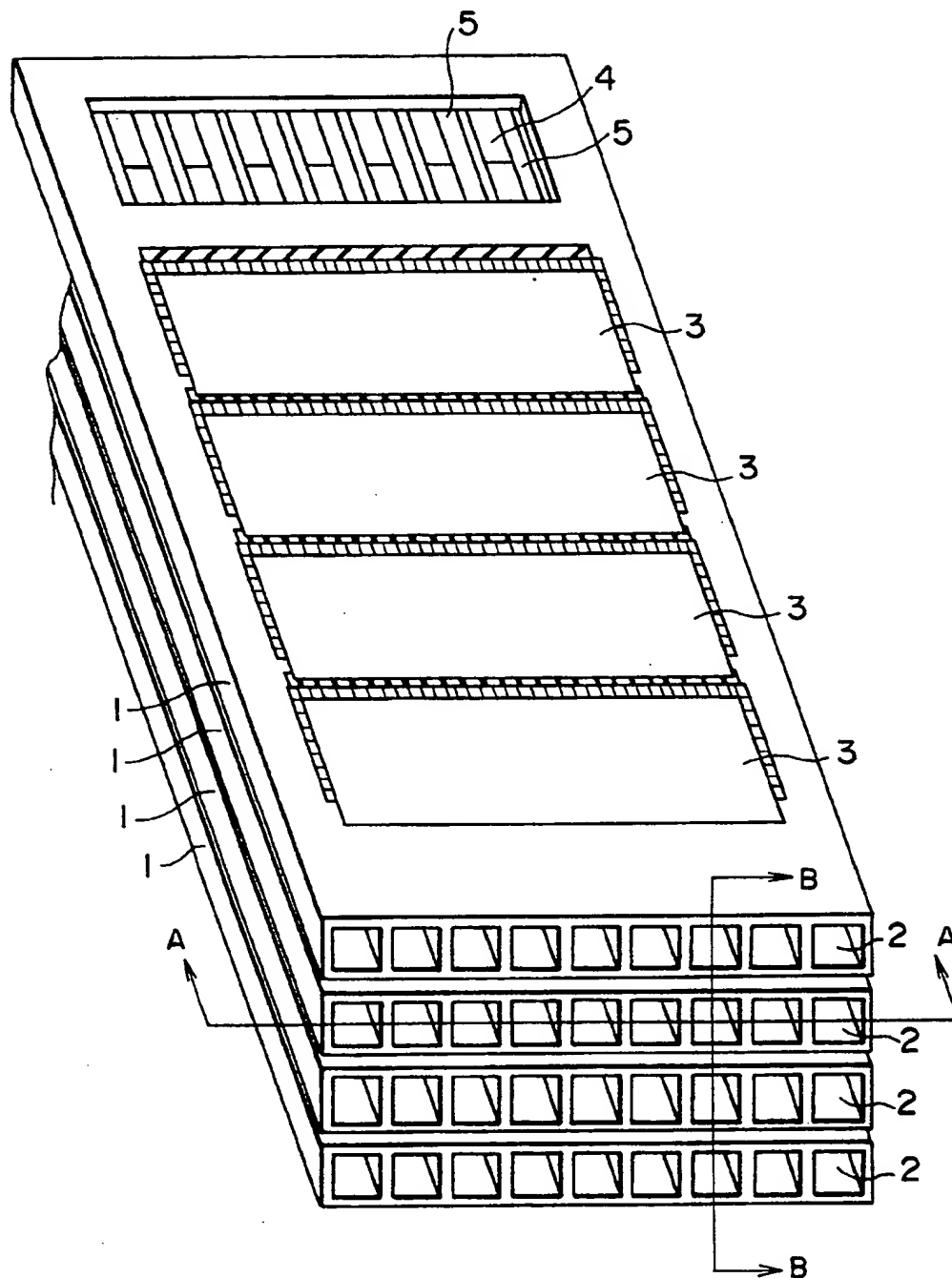


FIG. 7

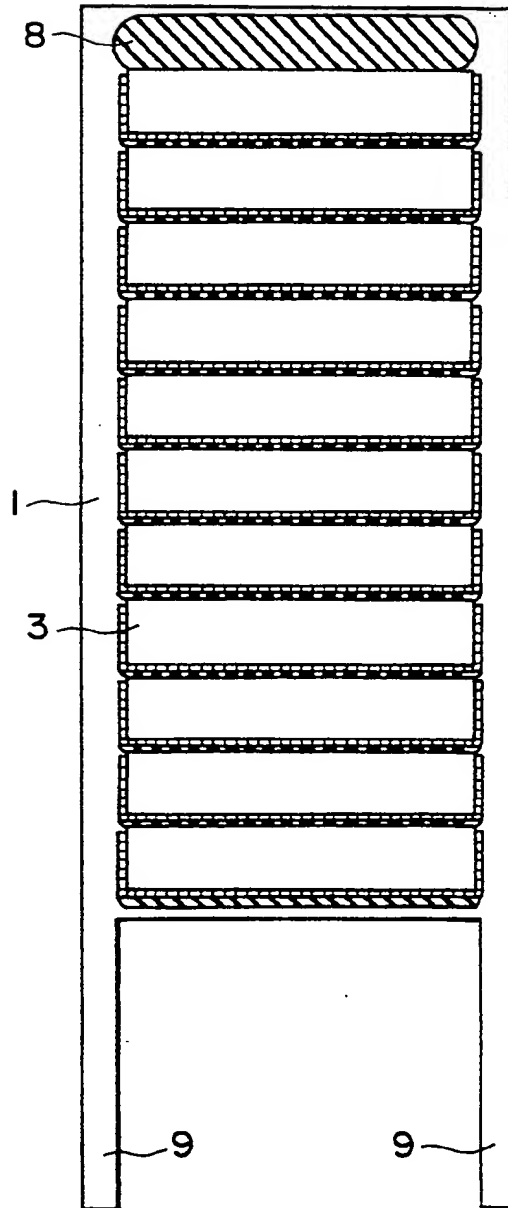


FIG. 8

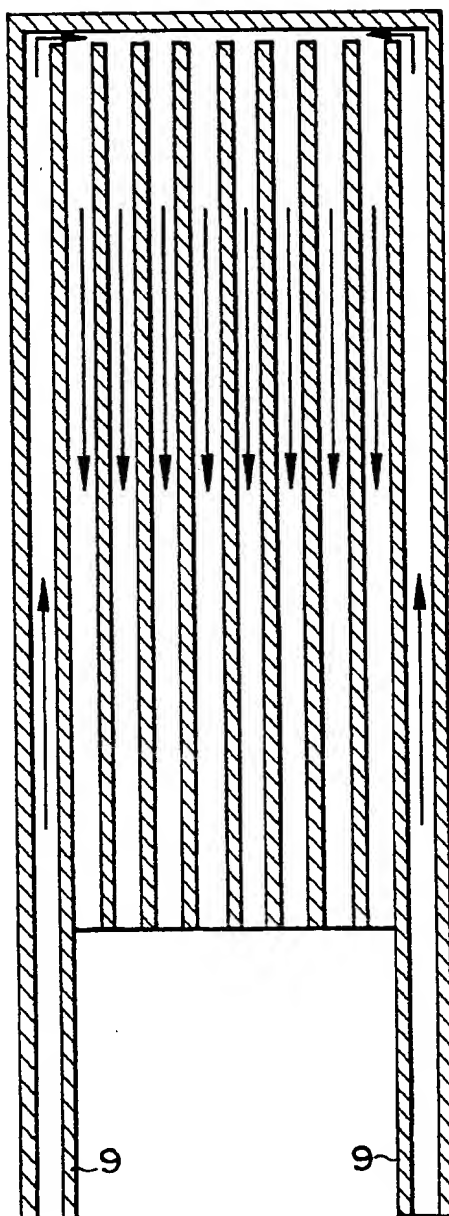


FIG. 9

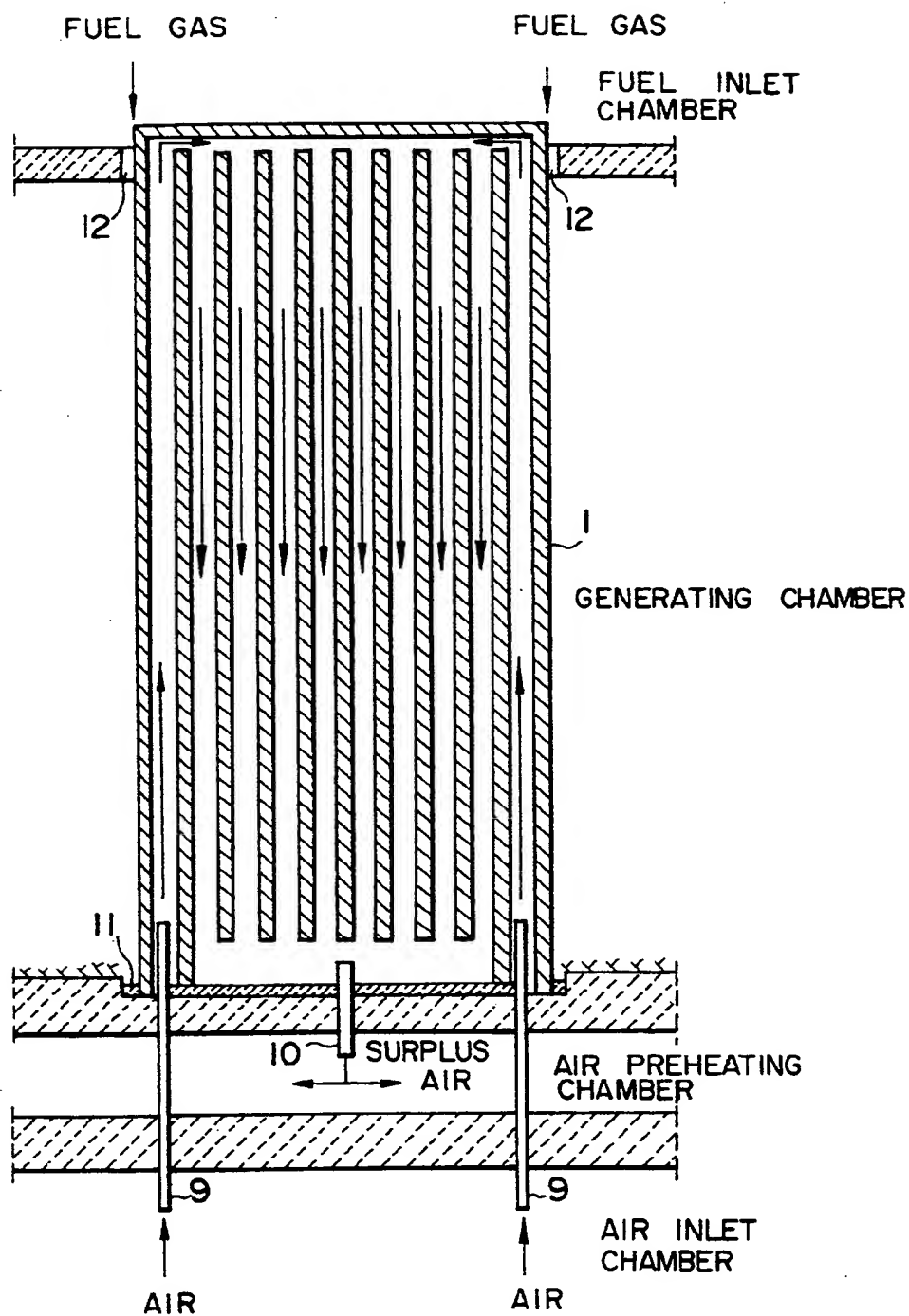


FIG. 10

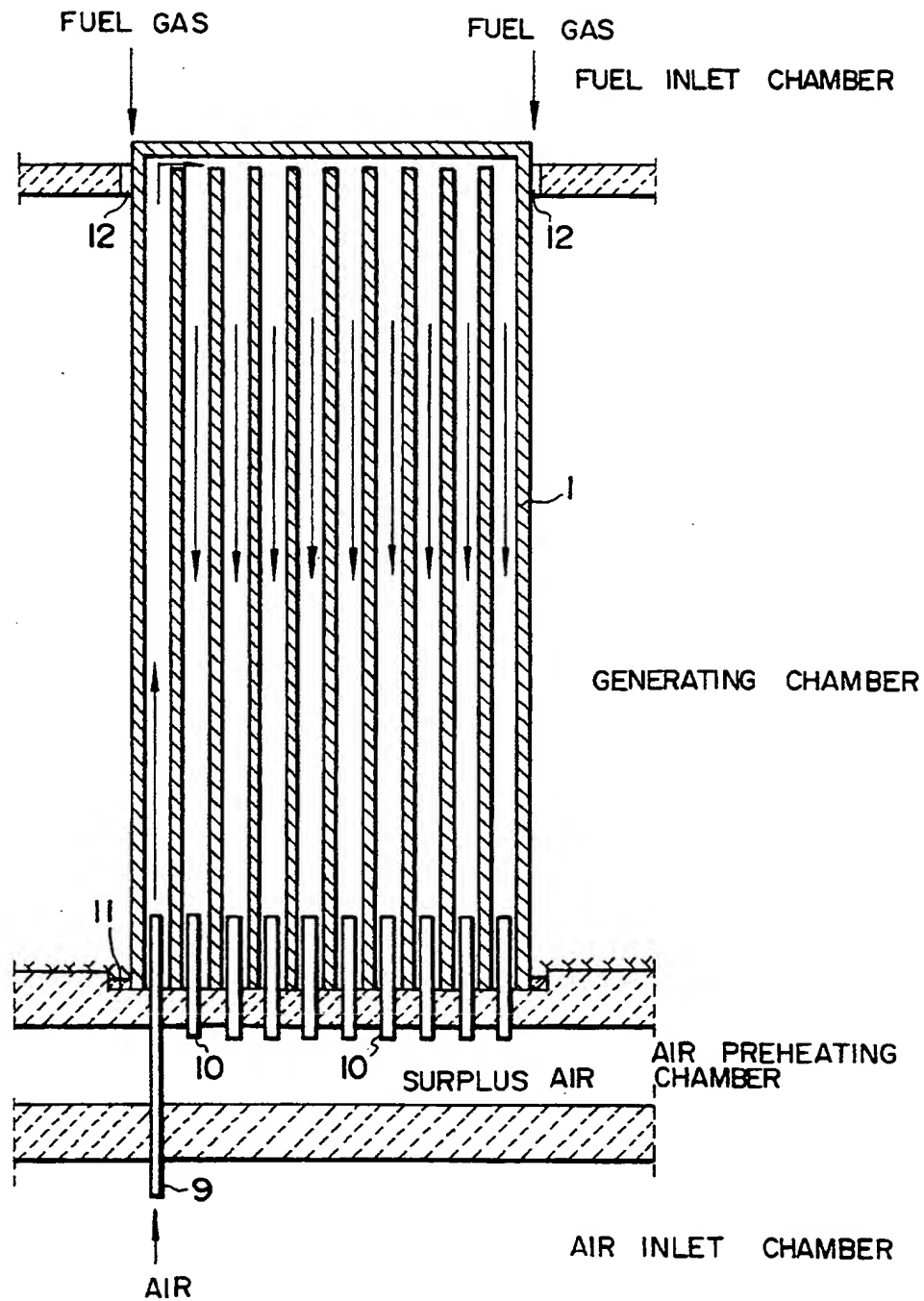


FIG. 11

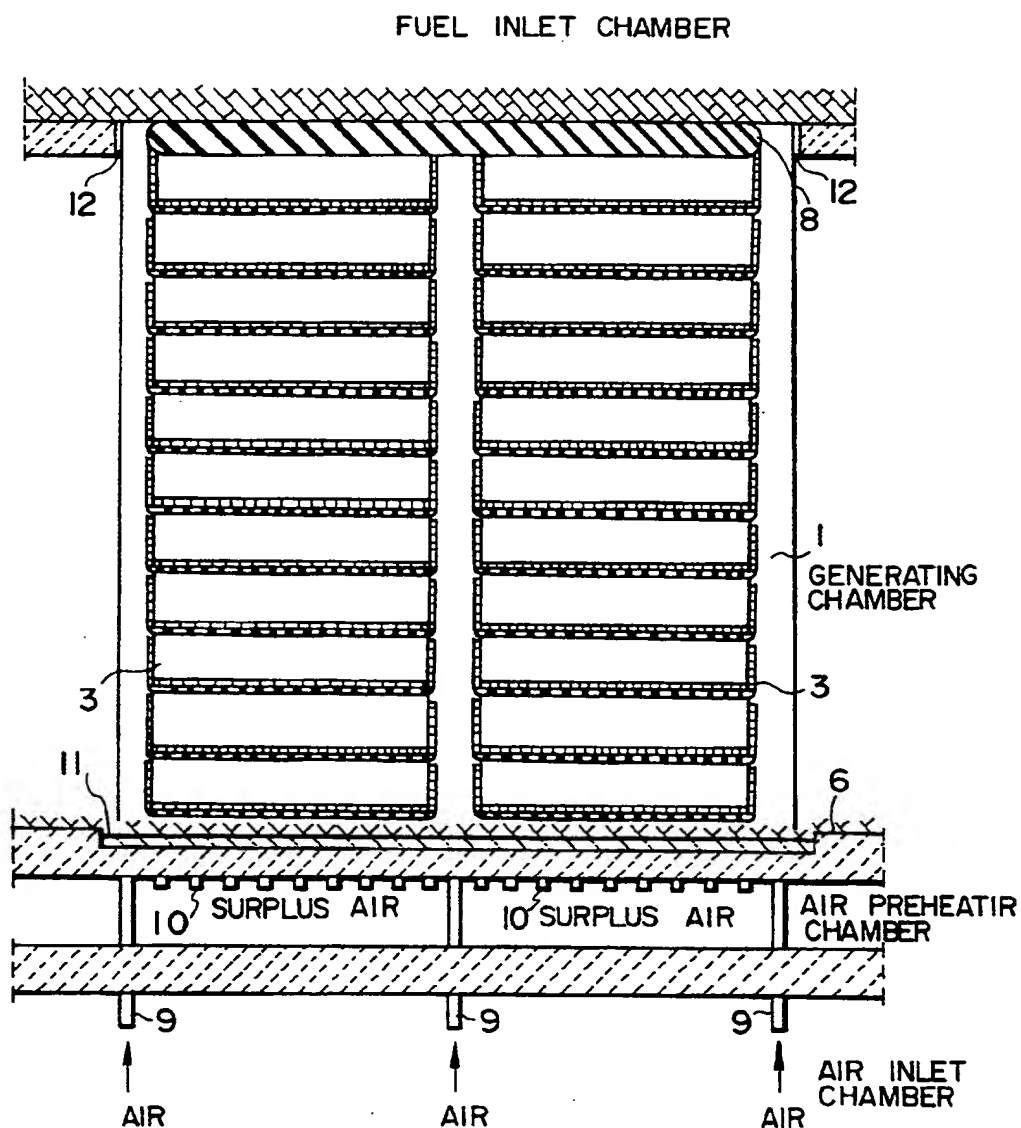


FIG. 12

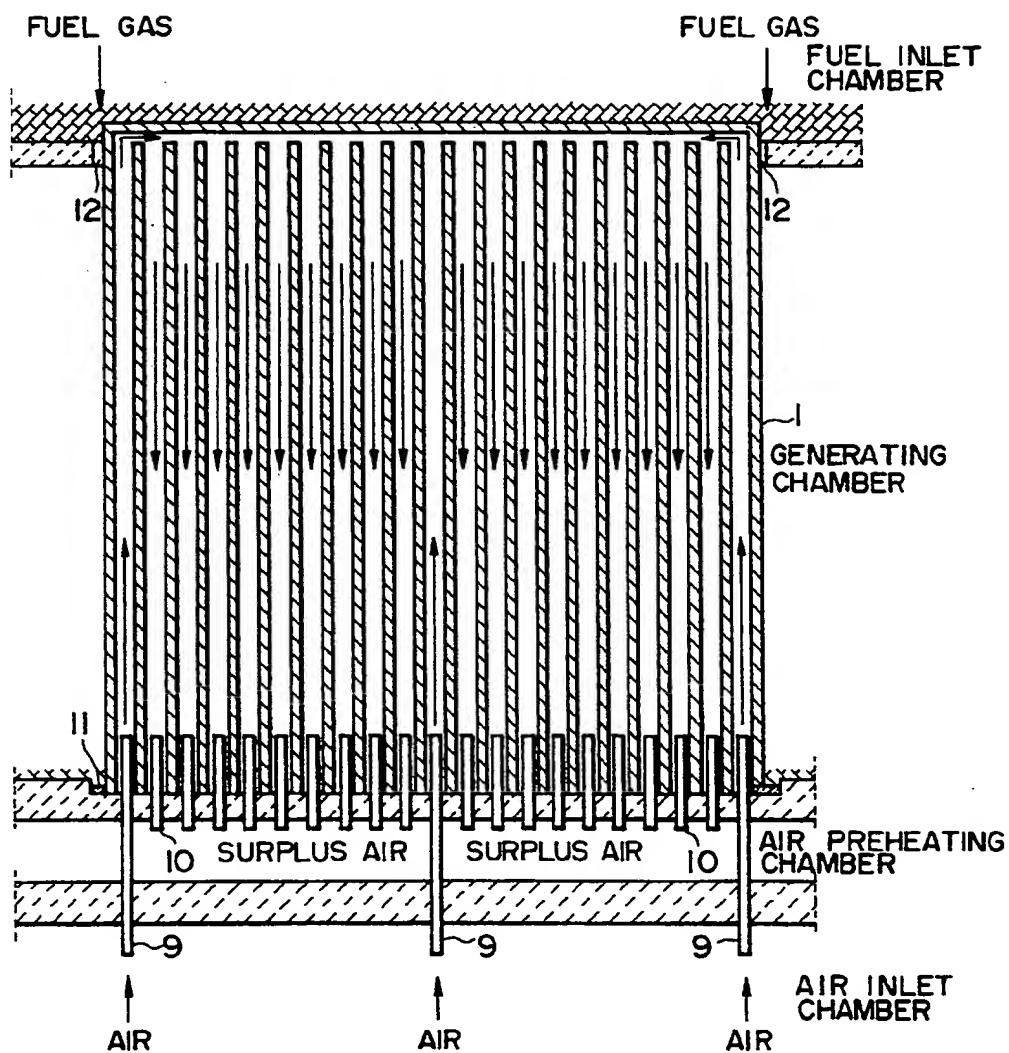
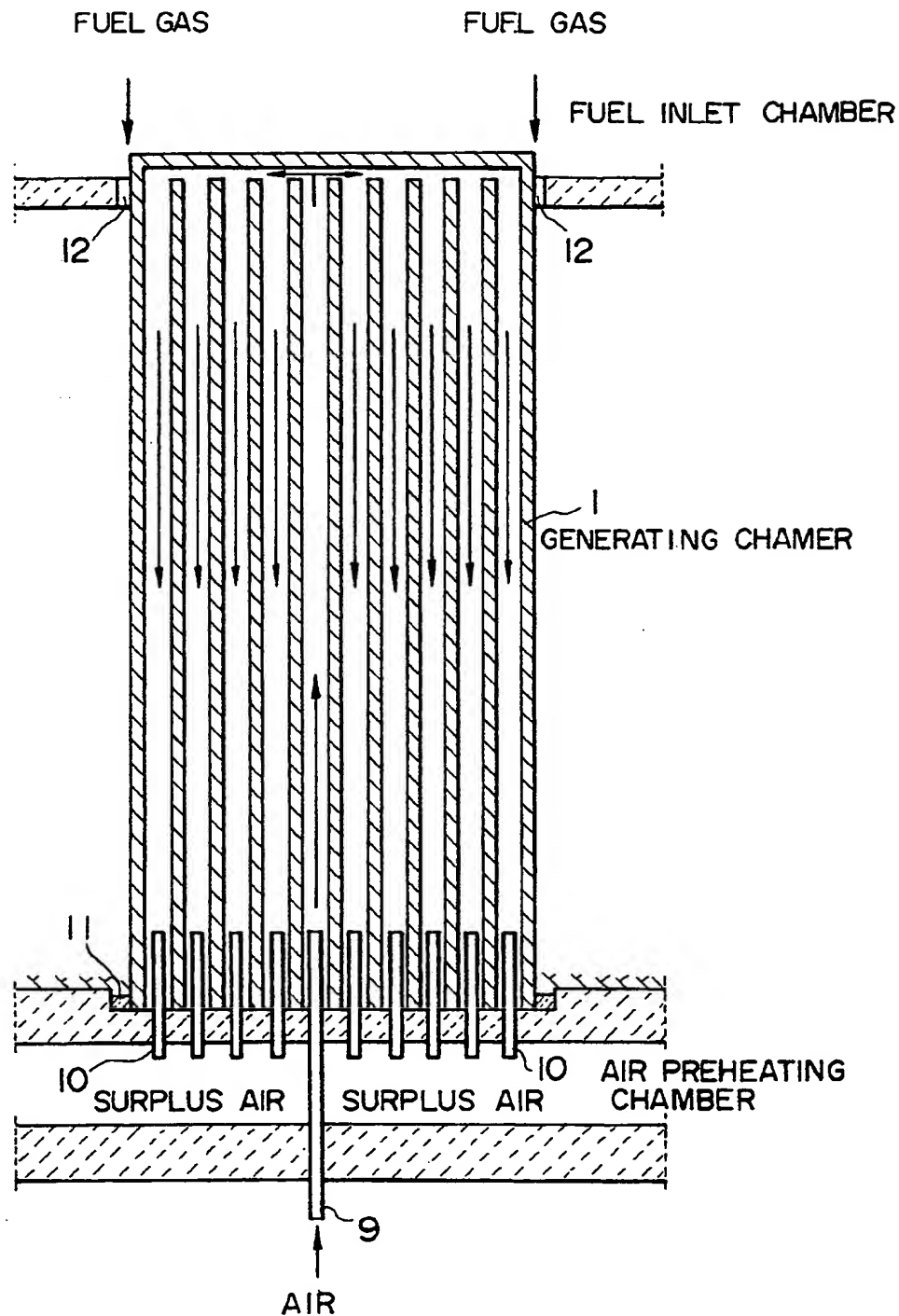


FIG. 13



SOLID OXIDE FUEL CELL GENERATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a generator using solid oxide fuel cells. More particularly, it relates to a generator capable of efficiently preheating a fuel or fuel assistant gas.

2. Description of the Prior Art

A solid oxide fuel cell (hereinafter referred to as a SOFC) is operated at a temperature of the order of 1000° C. Therefore, it is necessary to provide means for supplying a fuel or a fuel assistant gas into and means for discharging an unreacted or reacted gas out of a generating chamber.

Consequently, with an arrangement in which the substrate is combined a gas inlet part and a gas outlet part together with a cell mounting part, the cell section or the power generating section can be provided only at a mid portion of the substrate, thus leading to a poor areal efficiency with respect to the substrate and to an increased size of the structural unit. Besides, since the gas at a temperature of the order of room temperature is directly supplied to the cell section, the cell section tends to be cooled to lower the generating efficiency. The problem may considerably arise especially at a section where a fuel assistant gas, such as air, is supplied.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a fuel cell generator in which the areal efficiency with respect to the substrate is improved, and in which the generating efficiency is also improved by sufficient gas preheating.

According to the present invention, there is provided a solid oxide fuel cell generator comprising: a plurality of fuel cell mounting holes formed on the surface of a hollow dense substrate and having supports therein; and cell sections provided on recesses formed by the mounting holes and the supports, with adjacent cell sections being connected to each other by electrically conductive interconnections, in which a hollow longitudinal supply channel for supplying a fuel or fuel assistant gas is provided adjacent to the cell mounting holes in the substrate, the supply channel being kept at its other end in communication with hollow section of the substrate inside the cell sections. The supply channels is preferably provided on both lateral sides of the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view showing a solid oxide fuel cell generator according to the present invention.

FIG. 2 is a cross-sectional view taken along line A—A of FIG. 6.

FIG. 3 is a cross-sectional view taken along line B—B of FIG. 6.

FIG. 4 is an enlarged view showing an upper part of FIG. 3.

FIG. 5 is an enlarged view showing a lower part of FIG. 3.

FIG. 6 is a partly sectioned schematic perspective view showing the solid oxide fuel cell generator of the present invention.

FIG. 7 is a plan view showing a modification of the solid oxide fuel cell generator according to the present invention.

FIG. 8 is a sectional view of a substrate shown in FIG. 7.

FIG. 9 is a sectional view of a substrate modified from that shown in FIG. 2.

FIG. 10 is a sectional view of another substrate modified from that shown in FIG. 2.

FIG. 11 is a plan view showing a further modification of the solid oxide fuel cell generator according to the present invention.

FIG. 12 is a sectional view of a substrate shown in FIG. 11.

FIG. 13 is a sectional view of a further substrate modified from that shown in FIG. 12.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

More specifically, in contradistinction to the conventional generator in which both ends of a hollow section of a dense substrate, serving as a gas passage, are opened to permit a unidirectional gas flow, the solid oxide fuel cell generator of the present invention has hollow parts which are formed in the substrate, without contacting with cell sections, and are used as gas supply channels for a fuel or fuel assistant gas. The channels communicate, at their one end, with other hollow parts of the substrate on which cell sections are mounted. In this manner, the preheating and non-generating substrate areas provided in the conventional generator for preheating and introducing the gas to the inside of the substrate may be reduced and the substrate length is also reduced for the same generating area. Consequently, the size of the modular unit(stack) can be reduced.

In a preferred embodiment, the supply channel is provided on both lateral sides of the substrate. This not only obviates the problem of cooling of the generating section and the resultant lowering of the generating efficiency but also renders it unnecessary to use special components, such as preheating tubes. Also, in such a structure, both lateral sides of the substrate, which has heretofore been a dead zone (i.e., a zone free of the cell sections) for maintaining the integrity of a dense substrate, can be used as supply channels, thereby enhancing especially the areal efficiency while maintaining the integrity of the dense substrate.

In addition, since the substrate of the present invention is formed of a dense structure, it is unnecessary to cover the substrate portions other than the cell sections with a special gas seal film as opposed to the conventional system in which the cell sections are mounted onto a porous substrate and portions other than the cell sections are required to be covered with a special gas seal film. Therefore, in the present invention, the hollow part of the substrate may be used freely for gas preheating or the like. Furthermore, as one end of the substrate is closed in advance, gas sealing treatment between the substrate and a support element supporting the substrate in a chamber is required only at the lower end of the substrate as opposed to the conventional system in which the substrate is fixed and hermetically sealed at the both ends of the substrate. Consequently, the substrate is not applied thermal stress even when the geometrical difference between the substrate and its support element occurs due to the difference of thermal expansion coefficient, and the problems of destruction

of fixed part of the substrate and gas leakage at that part are solved drastically.

The present invention will be explained in more detail with reference to the following Examples.

EXAMPLES

The basic structure of the solid oxide fuel cell generator according to the present invention is, as schematically shown in a partially sectioned perspective view of FIG. 6, comprises a substrate 1 having plural hollow parts 2, a plurality of fuel cell mounting holes 4 formed on the surface of the substrate 1 and a plurality of supports 5 provided within each of the holes 4.

FIG. 1 is a plan view of the solid oxide fuel cell generator according to the present invention. A stack having a plurality of cell sections 3, which are mounted on a dense substrate 1 closed at its upper end, is sealed with fused glass 11 at its lower end and air is introduced into the inside of the substrate 1 via air inlet tubes 9 at both sides of the substrate 1, while a fuel gas, such as hydrogen, is caused to flow on an outer side of the substrate 1 from an upper fuel inlet chamber via fuel inlet openings 12. The cell sections 3 are connected in series with one another and generated electricity is collected by an anode 6 of nickel felt and a cathode 7 of nickel felt provided at the lower ends of a generating chamber and the fuel inlet chamber, as viewed in FIG. 1, respectively.

FIG. 2 is a cross-sectional view taken along line A—A of FIG. 6, that is, a cross-sectional view of the substrate 1 shown in FIG. 1. The cell section is not shown. Air supplied from the air inlet chamber is introduced via air inlet tubes 9 into both lateral sides of the substrate so that the air flows in hollow parts which are not contacted with the cell sections 3, with being preheated by heat transfer from the generation chamber, and, then, into an adjoining central flow channel.

The lateral sides of the substrate 1 are designed as a dead zone, that is, a zone free of the cell sections, for maintaining integrity of the dense substrate. This zone is used for preheating. Surplus air, which has passed through the central flow channel without being consumed, is discharged via air effluent tubes 10 into an air preheating chamber for further preheating the air inlet tubes 9. The air preheating effect may be further improved by introducing the spent fuel from the generating chamber into the air preheating chamber for combustion in the air preheating chamber.

FIG. 3 is a cross-sectional view taken along line B—B of FIG. 6, that is, a cross-sectional view through a mid part of FIG. 1. The cell section is not shown. In this manner, a large number of stacks may be arranged as shown.

FIG. 4 is an enlarged view showing an upper part of FIG. 3. Each of the stacks is supported by a partition wall between the fuel inlet chamber and the generating chamber, with the fuel gas being introduced into the generating chamber via an interstice provided in the partition wall. The nickel felt 7 is electrically connected with an air electrode formed at the topmost part of the cell section via an electrically conductive interconnection 8 and acts as a positive current-collecting terminal. If methane or the like is used as fuel, the nickel felt also act as a catalyst for the gas reforming. The partition wall is a guide wall for SOFC stacks and is not firmly contacted with these stacks. Therefore, the substrate is not subjected to destruction of the fixed part of the substrate and gas leakage at that part.

FIG. 5 is an enlarged view showing the lower part of FIG. 3. The stacks are each immersed in the fused glass 11 by their own gravity for establishing a gas seal between the air and fuel gas on the inner and outer sides of the substrate. Air inlet and discharge into and out of the stacks is effected through tubes passing through partition walls between the air preheating chamber and the generating chamber and between the air preheating chamber and the air inlet chamber. The nickel felt 6 provided above the fused glass 11 as viewed in FIG. 5 is electrically connected with a fuel electrode formed at the lowest part of the cell via the electrically conductive interconnection 8 so as to play the part of a negative current-collecting terminal.

FIG. 7 shows an modification in which the flow channels on both lateral sides of the substrate 1, not contacted with the cell sections 3 are extended to form air inlet tubes 9. The present modification is otherwise the same as the embodiment shown in FIGS. 1 and 2, although the common parts are not shown. FIG. 8 shows a transverse cross-section of the substrate 1 parallel to the substrate surface. The cell sections are not shown.

FIG. 9 shows, in a cross section of the substrate 1, another modification of the present invention in which only the flow channel construction differs from that of the preceding embodiments. The cell sections again are not shown. With the present modification, the lower ends, as viewed in FIG. 9, of the central flow channels of the substrate are opened for communication with one another, and a sole air effluent tube 10 is provided in the communicating zone.

FIG. 10 shows, by a transverse cross-section of the substrate 1, a further modification in which only one air inlet tube 9 is provided at a lateral side of the substrate 1. The cell section is not shown. The present modification is otherwise the same as in FIG. 2.

In a further modification shown in FIG. 11, the cell sections 3 are arranged in two parallel groups on the substrate 1, and neighboring inner air inlet tubes of the groups are combined into one central air inlet tube. FIG. 12 shows the transverse cross-section of the substrate showing the flow channel structures. The cell sections again are not shown. The present modification is otherwise the same as the embodiment shown in FIG. 2.

FIG. 13 shows a still further modification in which the air inlet tubes 9 on both lateral sides of the substrate 1 in FIG. 12 are eliminated to leave only the central air inlet tube. In FIG. 13, the cell sections again are not shown. The substrate is shown with a reduced width. In the present modification, the cell sections are arranged in two groups on both sides of the central air inlet tube. The present modification is otherwise the same as that shown in FIG. 2.

It will be seen from above that the present invention provides a solid oxide fuel cell generator in which the substrate is formed of a dense structure which has hollow parts providing supply channels for supplying a fuel or fuel assistant gas to cell sections and, hence, a sufficiently preheated gas is supplied to the cell sections to improve the generating efficiency without requiring the use of an extra gas supplying means or the like. Further, since the supply channels are provided at the lateral sides of the substrate, the areal efficiency of the generating section is greatly improved and molding of the substrate can be easily made at a lower production cost. Furthermore, since the substrate is closed at its one

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end and is supported only at its lower end by its own weight, any difficulty in gas sealing is eliminated.

What is claimed is:

1. A solid oxide fuel cell generator comprising:
 - a substrate having a plurality of longitudinal hollow 5 parts as gas flow channels, a closed end, and two lateral sides;
 - a plurality of cell mounting holes with supports therein formed on a surface of the substrate, the 10 cell mounting holes being adjacent to the gas flow channels;
 - a plurality of cell sections residing on the cell mounting holes and the supports, adjacent cell sections being connected to each other by electrically conductive interconnections; and

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wherein at least one of the gas flow channels formed in the substrate adjacent to the cell mounting holes serves as a gas supply channel for supplying a fuel or a fuel assistant gas from a first end opposite to the closed end, the at least one gas flow channel communicates with other gas flow channels of the substrate under the plurality of cell sections at the closed end of the substrate, and the fuel or fuel assistant gas is preheated at an air preheating chamber at the first end or by heat transfer while flowing in the gas flow channels.

2. The solid oxide fuel cell generator according to claim 1, wherein the supply channel is in both lateral sides of the substrate.

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US005589002A

United States Patent [19][11] **Patent Number:** **5,589,002****Su**[45] **Date of Patent:** **Dec. 31, 1996**

[54] **GAS DISTRIBUTION PLATE FOR SEMICONDUCTOR WAFER PROCESSING APPARATUS WITH MEANS FOR INHIBITING ARCING**

208222	9/1986	Japan	118/723 E
13573	1/1987	Japan	118/723 E
60875	3/1987	Japan	118/723 E
149964	6/1989	Japan	118/723 E
166728	7/1993	Japan	118/723 R

[75] **Inventor:** Yuh-Jia Su, Cupertino, Calif.

[73] **Assignee:** Applied Materials, Inc., Santa Clara, Calif.

Primary Examiner—Robert Kunemund
Assistant Examiner—Jeffrie R. Lund
Attorney, Agent, or Firm—John P. Taylor

[21] **Appl. No.:** 217,467

[22] **Filed:** Mar. 24, 1994

[51] **Int. Cl.⁶** **C23C 16/00**

[52] **U.S. Cl.** **118/723 E; 156/345; 204/298.07; 204/298.33**

[58] **Field of Search** **118/723 R, 723 E, 118/723 ER, 715; 219/121.4, 121.51, 121.52, 121.55; 204/298.07, 298.31, 298.33, 298.39, 280, 284; 156/345; 315/111.21, 111.31**

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5,445,699	8/1995	Kamikawa	156/345
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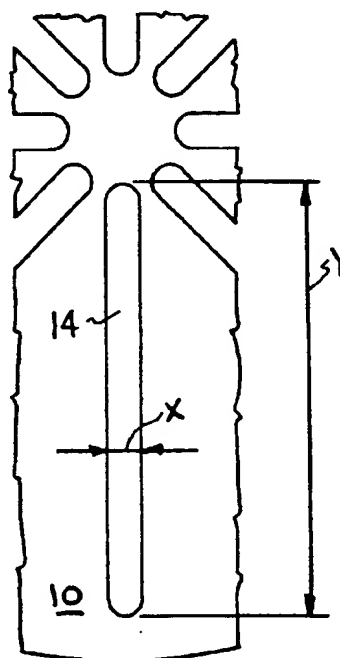
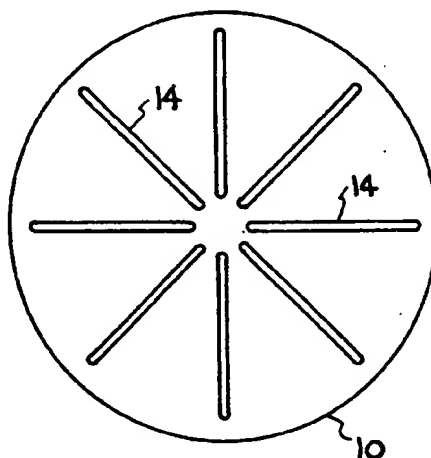
FOREIGN PATENT DOCUMENTS

104625 5/1986 Japan 204/298.33

[57] ABSTRACT

A gas distribution plate for a semiconductor wafer process chamber has a symmetrical pattern of non-circular openings formed therein for the passage of gas therethrough. The smaller axis of the non-circular openings should be at least about 127 μm (5 mils), and preferably at least about 254 μm (10 mils), but less than about 762 μm (30 mils), and preferably less than about 635 μm (25 mils). The larger axis is greater than the smaller axis, preferably at least about 635 μm (25 mils), and most preferably at least about 762 μm (30 mils). At least some of the walls of the non-circular openings are preferably not perpendicular to the plane of the face of the gas distribution plate, but are rather slanted, at an angle of from at least 30° to less than 90°, toward the center or axis of the outer face of the circular gas distribution plate which faces the wafer. Arcing on the face of the gas distribution plate may be further inhibited by providing peripheral conductive means on the face of the gas distribution plate electrically connected to grounded or neutral portions of the processing chamber to thereby provide a conductive path for unstable plasma at the surface of the gas distribution plate.

28 Claims, 3 Drawing Sheets



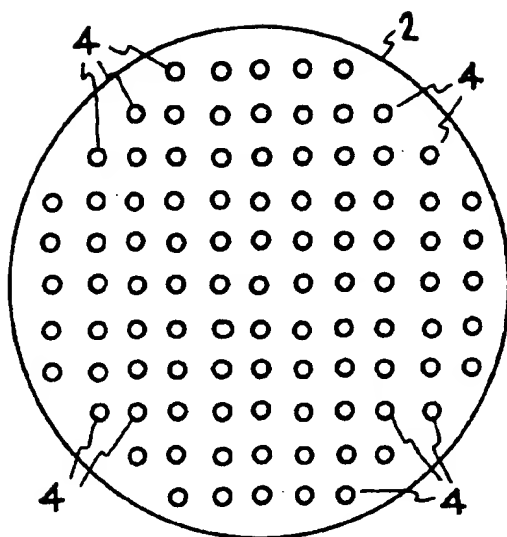


FIG. 1 (PRIOR ART)

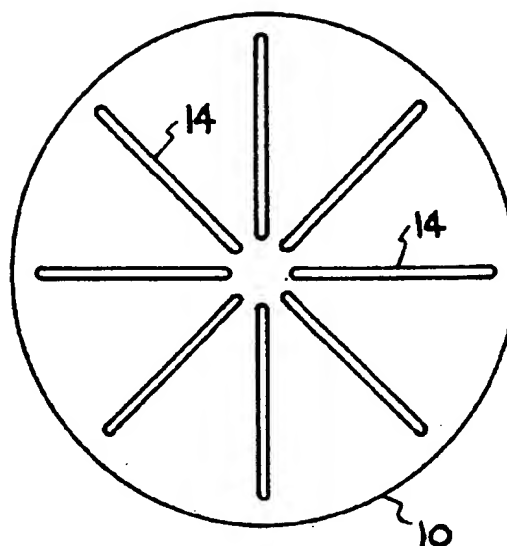


FIG. 2

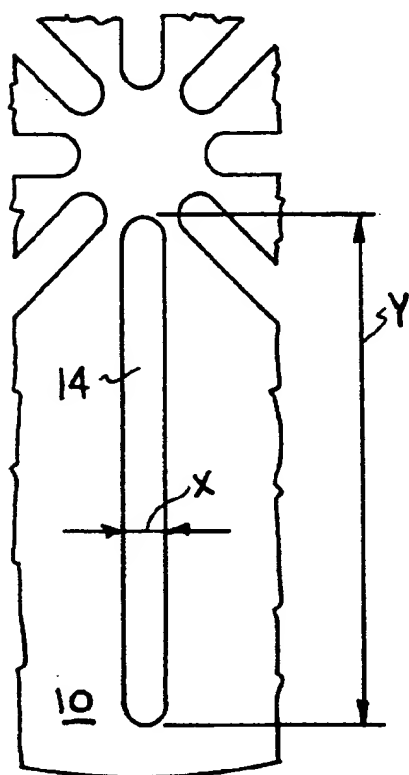


FIG. 3

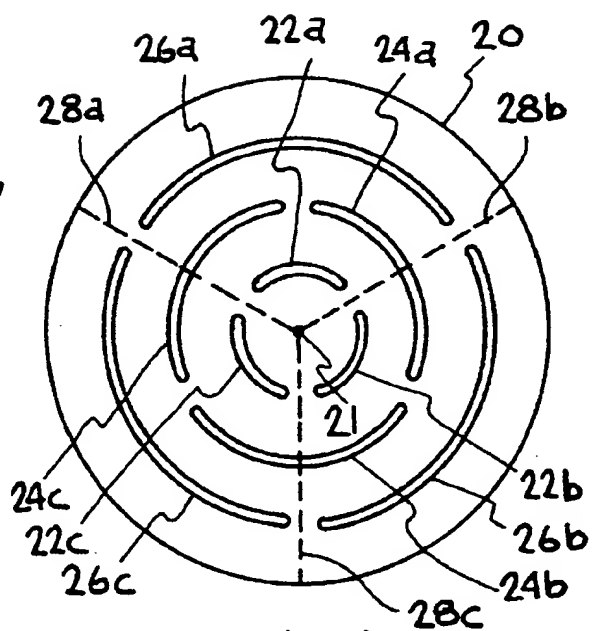


FIG. 4

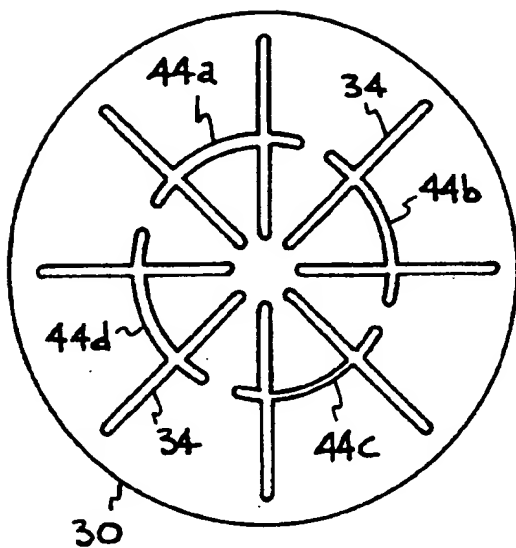


FIG. 5

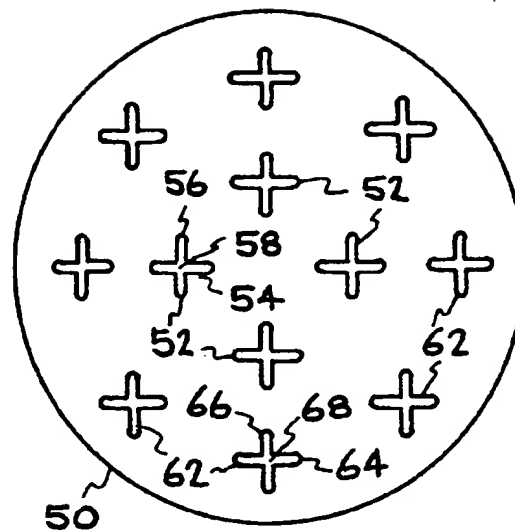


FIG. 6

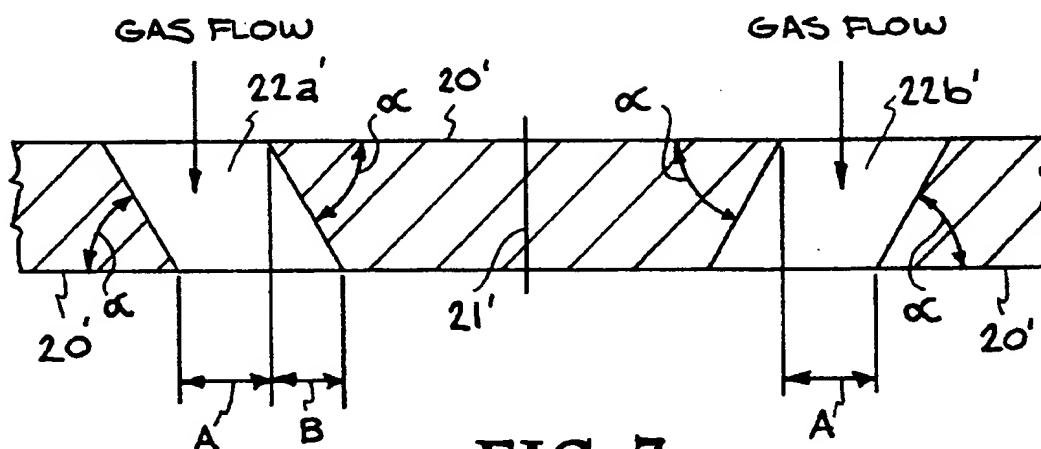
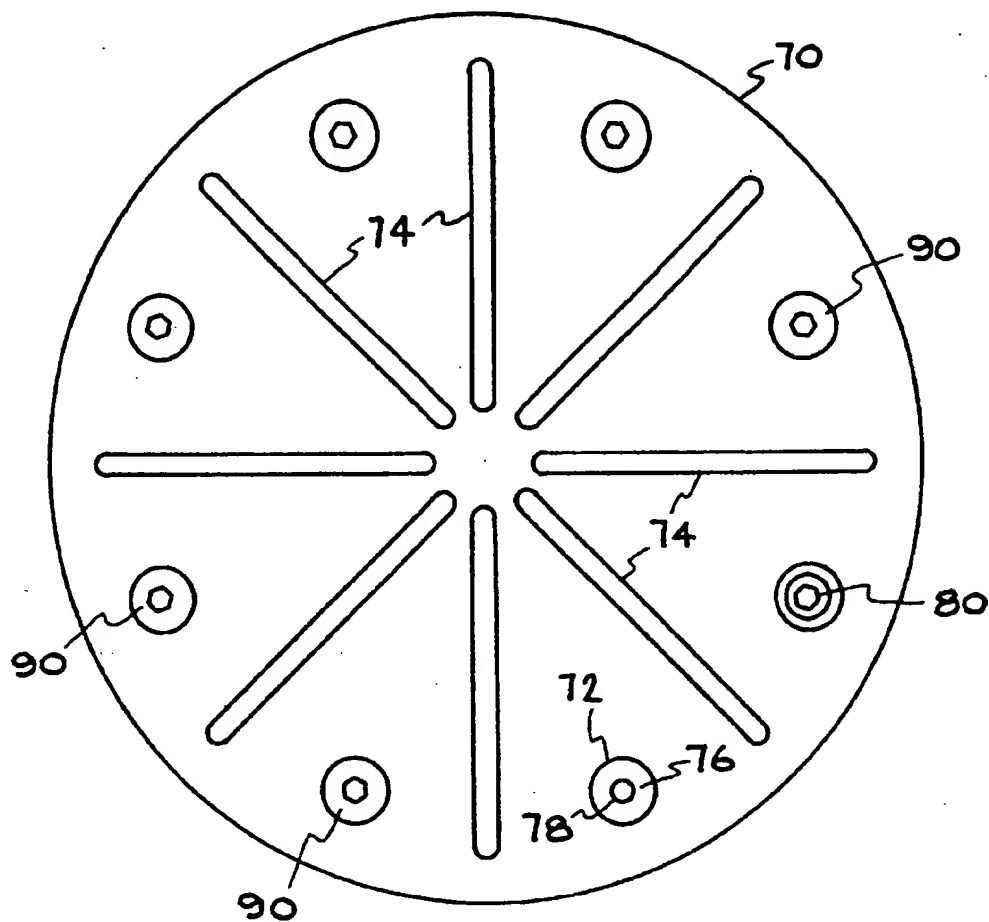
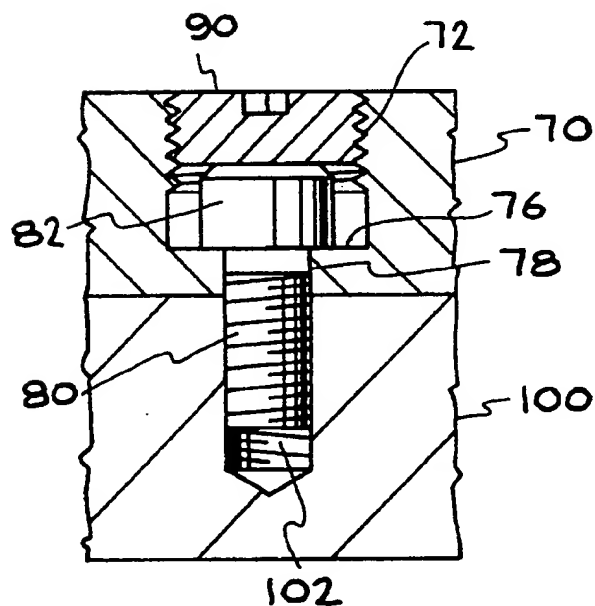


FIG. 7

**FIG. 8****FIG. 9**

GAS DISTRIBUTION PLATE FOR SEMICONDUCTOR WAFER PROCESSING APPARATUS WITH MEANS FOR INHIBITING ARCING

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to apparatus for processing semiconductor wafers, including an improved gas distribution plate used to introduce gas into a semiconductor processing chamber. More particularly, this invention relates to a gas distribution plate used to introduce gas into a semiconductor wafer processing chamber, which serves as an electrode when plasma processing is carried out in the chamber, and which contains means for inhibiting arcing at the gas distribution plate surface and means for inhibiting blockage of process gases passing through the gas distribution plate to the processing chamber.

2. Description of the Related Art

In the processing of semiconductor wafer, for example, to etch the wafer or to deposit a layer on material on the wafer surface, one or more gases are introduced into the processing chamber through openings in a gas distribution plate facing the wafer surface being processed. To assist in such etching or deposition, a plasma is often ignited in the chamber between the gas distribution plate and the wafer, for example, by electrically connecting the gas distribution plate to an RF power source, while grounding the metal walls of the chamber, as well as the wafer support on which the wafer rests during such processing.

The openings in the gas distribution plate, through which the processing gas flows into the chamber, are conventionally arranged in a symmetrical pattern of circular holes which are generally all of the same diameter to ensure even flow and distribution of the gases into the chamber. FIG. 1 shows such a prior art gas distribution plate 2 having a symmetrical arrangement of circular openings 4 formed therein.

While such a symmetrical pattern of identical circular openings generally serves to provide an even distribution of gas flow into the processing chamber, problems have been encountered with such circular openings. It has been found, for example, that the diameter of the circular openings must be maintained within a certain range which is not always convenient for the amount of desired gas flow into the processing chamber. If the diameter of the circular openings is less than about 508 micrometers (μm) or 0.020 inches (20 mils), the formation of by-products, by reaction of the halogen-containing plasmas with the wafer and/or chamber wall, will often result in blockage of at least some of the holes, resulting in either a reduced gas flow, or an unevenly distributed gas flow, or both, which may, in turn, affect process results.

On the other hand, the obvious solution to a blockage problem, i.e., increasing the diameter of the circular holes, can result in arcing on the gas distribution plate caused by the unstable plasma which can either flow along the face of the plate, or go into the gap between the plate and the lid or top of the processing chamber, if the diameter of the circular holes is about 762 μm (30 mils) or larger. This leaves a margin of less than about 254 μm (10 mils) in hole diameter between potential blockage of the openings, if the openings are too small, and potential arcing if the openings are too large.

It would, therefore, be desirable to provide a semiconductor processing apparatus suitable for use with plasma processing wherein the gas distribution plate of the apparatus was provided with a pattern of openings therein of sufficient size and shape to permit the flow of gas therethrough into the chamber, without blockage of the openings, regardless of the type of plasma generated in the chamber, while still inhibiting arcing of the plasma on the surface of the gas distribution plate and with a larger dimensional margin of opening sizes.

SUMMARY OF THE INVENTION

The invention comprises a semiconductor process chamber with a gas distribution plate having a symmetrical pattern of non-circular openings formed therethrough for the passage of gas therethrough. The smaller axis of the non-circular openings should be at least about 127 μm (5 mils), and preferably at least about 254 μm (10 mils), but less than about 762 μm (30 mils), and preferably less than about 635 μm (25 mils). The larger axis is greater than the smaller axis, preferably at least about 635 μm (25 mils), and most preferably at least about 762 μm (30 mils). In a preferred embodiment, at least some of the walls of the non-circular openings are not perpendicular to the plane of the face of the gas distribution plate, but are rather slanted, at an angle of from at least 30° to less than 90°, toward the center or axis of the outer face of the circular gas distribution plate which faces the wafer.

In another preferred embodiment, arcing around the gas distribution plate is further inhibited by providing peripheral conductive means on the face of the gas distribution plate electrically connected to grounded portions of the processing chamber to thereby provide a path to ground for unstable plasma at the surface of the gas distribution plate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top view of the pattern of circular openings arranged in a symmetrical pattern in a prior art gas distribution plate.

FIG. 2 is a top view of a symmetrical pattern of non-circular openings formed in a gas distribution plate of the invention.

FIG. 3 is a fragmentary enlarged top view of a portion of the gas distribution plate of FIG. 2 showing the width and length of one of the non-circular openings. FIGS. 4-6 are top views of other symmetrical patterns of non-circular openings formed in gas distribution plates of the invention.

FIG. 7 is a fragmentary vertical cross-sectional view of a portion of a gas distribution plate similar to the embodiments shown in FIGS. 4 and 5, but showing another embodiment of the invention wherein some of the walls of the non-circular openings are not formed perpendicular with the plane of the face of the gas distribution plate of the invention.

FIG. 8 is a top view of another aspect of the invention wherein conductive members are placed in the peripheral openings formed in the face of the gas distribution plate to receive mounting bolts which secure the plate to the lid or top of the processing chamber.

FIG. 9 is a fragmentary vertical cross-sectional view of a portion of the gas distribution plate structure of FIG. 8 showing one of the conductive members mounted in the bore which receives a mounting bolt to secure the gas distribution plate to the lid or top of the processing chamber.

DETAILED DESCRIPTION OF THE INVENTION

Turning now to FIGS. 2 and 3, one embodiment of the improved gas distribution plate of the invention is shown. In this embodiment, a circular gas distribution plate 10 is provided with a series of elongated slots 14, i.e., non-circular openings, arranged in a star-like pattern with the major axis of each slot passing through the center point or axis of plate 10. As best seen in FIG. 3, each slot has a major axis Y and a minor axis X. The minimum length Y of each slot 14 should be greater than the maximum width X of slot 14, and should be at least about 635 μm (25 mils), preferably at least about 762 μm (30 mils). The maximum length Y of slot 14 is governed only by the size (diameter) of plate 10. That is, the maximum length Y of slot 14 must be less than the radius of plate 10. The minimum width X of slot 14 should be at least about 127 μm (5 mils) and preferably will be at least about 254 μm (10 mils) to inhibit blockage of gases passing therethrough. The maximum width X of slot 14, however, will be less than 762 μm (30 mils), and preferably will be less than about 635 μm (25 mils) to inhibit arcing.

Such elongated and non-circular slots 14 have been found to provide an adequate opening for the passage of gas therethrough without blockage and without resulting in arcing from an oversize opening as was experienced with circular slots which exceeded 762 μm (30 mils) in diameter.

FIG. 4 shows another embodiment of the invention wherein a gas distribution plate 20 is provided with non circular openings which are in the form of arcs or arcuate slots of various radii coaxially arranged on circular gas distribution plate 20 with respect to center 21 of plate 20. In the illustrated embodiment, three arcuate slots 22a, 22b, and 22c are provided in an inner circular arrangement coaxial with the center of plate 20, with each arcuate slot occupying just less than 120° (so that the slots are separated from one another). Three arcuate slots 24a, 24b, and 24c are similarly arranged in a second coaxial circle of larger radius than that defined by arcuate slots 22a, 22b, and 22c; and three arcuate slots 26a, 26b, and 26c are coaxially provided in the largest of the three circles. It will, of course, be understood that more (or less) than three circles of arcuate slots may be provided if desired and/or needed to provide sufficient and uniform distribution of the gas flowing through the arcuate slots into the processing chamber. It should also be noted that more than three arcuate slots may be provided in each circle, provided that symmetry is maintained to thereby permit even distribution of the gas through the slots into the chamber.

Furthermore, as shown in FIG. 4, in this embodiment the three respective gaps between the three arcuate slots lying in the smallest circle preferably will be aligned with the three respective gaps between the three arcuate slots lying in the largest circle; and the three respective gaps between the arcuate slots lying in the middle circle will be rotated 60° from the gaps between the respective slots in the one innermost and outermost circles. The centers of the respective gaps between the three arcuate slots lying in the innermost and outermost circles will then be positioned on respective radii which intersect the midpoint of the corresponding arcuate slots lying in the middle circle, as shown in the dotted lines 28a, 28b, and 28c in the preferred arrangement of this embodiment.

As in the previous embodiment, the width of each of the arcuate slots should range from a minimum of at least about 127 μm (5 mils), and preferably at least about 254 μm (10

mils), to inhibit blockage of gases passing therethrough; up to a maximum width of less than 762 μm (30 mils), and preferably less than about 635 μm (25 mils) to inhibit arcing.

The range of circumferential length of the arcuate slots will, of course be dependent upon which of the three circles the particular arcuate slot lies in. However, the minimum length of all of the slots, regardless of which circle the slots lie in, will be greater than the width of the slots and at least greater than about 635 μm (25 mils), and preferably at least greater than about 762 μm (30 mils).

The maximum circumferential length of each of the three arcuate slots lying in each circle will be less than $\frac{1}{2}$ of the diameter of that circle. Thus, for example, when three circles of three arcuate slots each are provided, with the midpoint of the respective widths of the slots equidistant from one another as well as from the outer edge and the center of the circular gas distribution plate, as in the illustration of FIG. 4, the maximum circumferential length of each of the three arcuate slots lying in the inner or smallest circle (slots 22a, 22b, and 22c) will be less than $\frac{1}{2}\pi$ ($\frac{1}{2}D$), where D is the diameter of the gas distribution plate; the maximum circumferential length of each of the three arcuate slots lying in the middle circle (slots 24a, 24b, and 24c) will be less than $\frac{1}{2}\pi$ ($\frac{1}{2}D$); and the maximum circumferential length of each of the three arcuate slots lying in the outermost circle (slots 26a, 26b, and 26c) will be less than $\frac{1}{2}\pi$ ($\frac{1}{2}D$). Of course, if more or less than three arcuate slots are used in each circle, the maximum length of each arcuate slot will be modified accordingly. For example, if four arcuate slots were provided in the innermost of three circles, the maximum length of each would be less than $\frac{1}{4}\pi$ ($\frac{1}{4}D$).

FIG. 5 illustrates yet another embodiment which incorporates the features of the embodiment of FIGS. 2 and 3 with some features similar to the arcuate slots of the embodiment of FIG. 4. Thus, gas distribution plate 30 of FIG. 5 is provided with radiating slots 34 having the same range of dimensions as slots 14 of FIG. 2 and 3; and coaxially positioned arcuate slots 44a, 44b, 44c, and 44d having, in the preferred arrangement of this embodiment, the same width dimensions as arcuate slots 24a, 24b, and 24c of the embodiment of FIG. 4, and each having a length of less than $\frac{1}{4}\pi$ ($\frac{1}{4}D$), where the value of x would depend upon the diameter of the circle defined by the coaxially positioned arcuate slots 44a-44d and D is the diameter of gas distribution plate 30. As shown in FIG. 5, preferably each of the four arcuate slots 44a-44d would have a maximum length of less than $\frac{1}{4}\pi$ ($\frac{1}{4}D$), i.e., the diameter of the circle defined by arcuate slots 44a-44d would be half of the diameter D of gas distribution plate 30 so that arcuate slots 44a-44d would be equidistance from the center and outer edge of plate 30.

Yet another embodiment is shown in FIG. 6, wherein gas distribution plate 50 is provided with crossed slots 52 and 62, with the intersections of the respective crossed slots lying in either a smaller or larger circle around the midpoint of plate 50. Thus, each of the four crossed slots 52 having intersections lying along the inner circle comprise a horizontal slot 54, a vertical slot 56, and an intersection 58; while each of the eight crossed slots 62 having intersections lying along the outer circle comprise a horizontal slot 64, a vertical slot 66, and an intersection 68.

As in the embodiment of FIGS. 2 and 3, the respective width of slots 54, 56, 64, and 66 should be at least about 127 μm (5 mils) and preferably will be at least about 254 μm (10 mils) to inhibit blockage of gases passing therethrough; while the maximum width of the slot, however, will be less than 762 μm (30 mils), and preferably less than about 635 μm (25 mils) to inhibit arcing.

The respective lengths of slots 54, 56, 64, and 66 will be at least greater than the maximum width of the slots, and should be at least about 635 μm (25 mils), preferably at least about 762 μm (30 mils). The maximum length of slots 54, 56, 64, and 66 will depend upon the overall dimensions of plate 50, but will preferably each not exceed about $\frac{1}{4}$ of the radius of plate 50.

Although it is preferable that all of the slots be of the same length and width, to preserve symmetry and resultant uniform delivery of gas through the openings into the chamber, it is not necessary that the lengths and widths be identical as long as the respective lengths and widths of the slots define a symmetrical pattern which will provide the desired uniform delivery of gas into the chamber.

When two circles of crossed slots are used, as in the illustrated structure of FIG. 6 of this embodiment, intersections 58 of inner crossed slots 52 should preferably lie along a circle having a diameter of about $\frac{1}{2}$ of the diameter of plate 50, while intersections 68 of outer crossed slots 62 should preferably lie in a circle having a diameter of about $\frac{3}{4}$ of the diameter of plate 50, to provide optimum symmetrical spacing of the respective crossed slots on plate 50. It will be appreciated that more than two circular arrangements of such crossed slots may be used, as long as a symmetrical arrangement is used which will provide uniform gas distribution therethrough into the processing chamber.

Turning now to FIG. 7, a further embodiment is shown comprising a modification of the embodiments of FIGS. 4 and 5, wherein the arcuate slots, i.e., the slots which perpendicularly intersect a radius of the gas distribution plate, are provided with slanted or angled sidewalls, rather than sidewalls perpendicular to the face of the gas distribution plate. By providing such angled sidewalls, i.e., slanted across the width or shorter dimension of the slot, the total width of the arcuate slot (A+B in FIG. 7) may be made wider than the maximum permitted width of a perpendicular slot without increasing the risk of arcing as long as the lateral width (A in FIG. 7) does not exceed the previously recited maximum width of the slots, i.e., is less than 762 μm (30 mils), and preferably less than about 635 μm (25 mils).

Thus, as shown in FIG. 7, arcuate slots 22a' and 22b' are shown formed in gas distribution plate 20' with sidewalls sloped at an angle α with respect to the surface of plate 20', where angle α is at least 30°, but is less than 90°, and preferably ranges from about 45° to about 75°. The sidewalls of arcuate slots 22a' and 22b' are angled toward center point 21' of gas distribution plate 20' on the delivery side of the plate, i.e., the face of the plate facing the wafer to be processed.

When such arcuate slots are formed with slanted sidewalls, the total width of slot 22a' (or slot 22b') is A+B, but the lateral width is only A. Thus, it will be seen that when the above discussed maximum lateral width A is maintained for slanted slots 22a' and 22b' (to inhibit arcing), the overall width A+B may exceed this value, thus increasing the overall gas flow through the slots without, however, increasing the risk of undesirable arcing. It should be noted that there is no minimum value of A, since distribution plate 20' may be made thick enough so that the entire lateral width of the slot comprises the value of B.

Turning now to FIGS. 8 and 9, yet another embodiment of the invention is illustrated which may be incorporated into the design of the gas distribution plate as a supplement to any of the previously described embodiments, or even used independently in the construction and use of the gas distribution plate, i.e., with a conventional gas distribution

In this embodiment, a gas distribution plate 70, which may optionally be provided with slots 74 similar to the embodiment of FIG. 2, is provided with openings or bores 72 to receive threaded mounting bolts 80 therein to secure plate 70 to a top plate 100 of the processing chamber which may constitute a removable lid or cover. As best seen in FIG. 9, a smaller counterbore 78 is also provided in plate 70 which intersects bore 72 to provide a shoulder 76 to receive head portion 82 of mounting bolt 80. A threaded bore 102 in top plate 100 coaxially aligned with bores 72 and 78 receives threaded mounting bolt 80 to secure gas distribution plate 70 to top plate 100 of the processing chamber.

It should be noted that the above described mounting arrangement is not new per se, but rather is used at present with prior art gas distribution plate structures. However, in prior art structures, each bore 72 was provided with an insulated plug to prevent plasma from traveling to the grounded walls of the chamber through the conductive, e.g., stainless steel, mounting bolts in bores 72, or the exposed sidewalls and bottom of bore 72, since the surface of aluminum distribution plate 70 is usually anodized to provide an insulated surface coating on the distribution plate.

However, in accordance with the invention, each bore 72, after the insertion and securement of mounting bolt 80 therein, is provided with a conductive plug 90 which is in electrical communication with either head 82 of mounting bolt 80, or the sidewalls of bore 72, or both, to thereby provide a path to ground or a neutral point for stray plasma currents flowing along the surface of gas distribution plate 70.

Conductive plug 90 may be formed of any type of conductive material which will be non-reactive with the processing being carried out in the chamber, e.g., etching or deposition processes. Preferably, the non-reactive conductive material will be a non-metallic material to minimize any possibility of reaction of the conductive material of plug 90 with gases or other processing materials being used in the semiconductor processing chamber. Examples of such non-reactive non-metallic conductive materials include silicon nitride, silicon carbide, silicon (with or without doping), graphite, and glassy carbon. It should be noted that for purposes of defining the above-described non-reactive, non-metallic, conductive filler material, silicon will be deemed to be non-metallic.

To further illustrate the invention, a 200 mm (8 inch) diameter gas distribution plate was constructed having a non-circular slot pattern of openings therein, in accordance with the invention, similar to that shown in FIG. 4, but with five circles of four arcuate slots each, with the sidewalls of the arcuate slots slanted toward the center of the outer face of the plate at an angle α of about 45°. The midpoints of the respective widths of the five circles of slots had respective diameters of 25.4 mm (1"), 50.8 mm (2"), 76.2 mm (3"), 101.6 mm (4"), and 127 mm (5"). The width of each of the arcuate slots (dimension A+B in FIG. 7) was about 40 mils. This gas distribution plate was installed in a semiconductor wafer processing chamber and used in an etch process with dummy wafers using a halogen-containing gas plasma for a total processing time period of about 24 hours (equal to processing time for about 750–100 wafers). The gas distribution plate was then removed and examined. No evidence of blockage of any of the holes was evident, nor any evidence of any arcing.

Thus, the invention provides a gas distribution plate having a symmetrical pattern of non-circular openings formed therethrough for the passage of gas therethrough to

provide for the passage of processing gas therethrough while inhibiting blockage of the openings and arcing on the plate. In a preferred embodiment, at least some of the walls of the non-circular openings are not perpendicular to the plane of the face of the gas distribution plate, but are rather slanted, at an angle of from at least 30° to less than 90°, toward the center or axis of the outer face of the circular gas distribution plate which faces the wafer; and in another preferred embodiment, arcing on the face of the gas distribution plate is further inhibited by providing peripheral conductive means on the face of the gas distribution plate electrically connected to grounded or neutral portions of the processing chamber to thereby provide a conductive neutralization or grounding path for unstable plasma at the surface of the gas distribution plate.

Having thus described the invention what is claimed is:

1. A gas distribution plate for a semiconductor processing apparatus which permits the flow of process gas into said processing apparatus while inhibiting arcing adjacent said plate during plasma processing comprising a plurality of non-circular openings in said gas distribution plate, each of said non-circular openings having:

a) a width:

- i) smaller than the diameter at which arcing will occur with circular openings; but
- ii) at least about 254 μm (10 mils) to inhibit blockage by a halogen-containing plasma; and

b) a length greater than said width.

2. The gas distribution plate of claim 1 wherein said plurality of non-circular openings in said gas distribution plate for inhibiting arcing adjacent said plate during said plasma processing further comprises a symmetrical pattern of said non-circular openings in said plate through which gas may flow into said processing apparatus.

3. The gas distribution plate of claim 1 wherein each of said non-circular openings in said plate has a width less than 762 μm (30 mils).

4. The gas distribution plate of claim 1 wherein each of said non-circular openings in said plate has a width of less than about 635 μm (25 mils).

5. A generally circular planar gas distribution plate for a semiconductor processing apparatus having structure for inhibiting arcing adjacent said plate during plasma processing comprising a symmetrical pattern of elongated slots in said plate through which gas may flow into said processing apparatus, each of said elongated slots having a major axis and a minor axis smaller than said major axis, said minor axis having a length:

- a) smaller than the diameter at which arcing will occur with circular openings; and
- b) larger than the diameter at which a halogen-containing plasma will block said circular openings.

6. The gas distribution plate of claim 5 wherein said major axis of at least a portion of said elongated slots intersect a midpoint of said circular plate.

7. The gas distribution plate of claim 5 wherein at least a portion of said non-circular openings comprise elongated slots having a major axis generally perpendicular to a line intersecting a midpoint of said circular plate.

8. The gas distribution plate of claim 7 wherein said elongated slots having a major axis perpendicular to a line intersecting a midpoint of said circular plate comprise arcuate slots lying in one or more circles coaxial to said midpoint.

9. The gas distribution plate of claim 5 wherein a portion of said elongated slots comprise first elongated slots having a major axis intersecting a midpoint of said circular plate; a

portion of said elongated slots comprise second elongated slots having a major axis generally perpendicular to a line intersecting said midpoint of said circular plate; and each of said first elongated slots intersects at least one of said second elongated slots.

10. The gas distribution plate of claim 9 wherein said second elongated slots comprise arcuate slots arranged in circles coaxial to said midpoint of said plate.

11. A generally circular gas distribution plate for a semiconductor processing apparatus having structure for inhibiting arcing adjacent said plate during plasma processing comprising a symmetrical pattern of non-circular openings in said plate through which gas may flow into said processing apparatus, each of said non-circular openings having a first dimension smaller than about 762 μm (30 mils) to inhibit arcing, but at least about 508 μm (10 mils) to inhibit blockage by a halogen-containing plasma; and a second dimension larger than said first dimension.

12. The gas distribution plate of claim 11 wherein said non-circular openings comprise a plurality of elongated slots wherein said second dimension of each slot is greater than 762 μm (30 mils).

13. The gas distribution plate of claim 11 wherein said non-circular openings comprise a plurality of elongated slots lying along lines which intersect a midpoint of said circular plate.

14. The gas distribution plate of claim 11 wherein said non-circular openings comprise a plurality of arcuate slots lying in one or more circles coaxial with a midpoint of said circular plate.

15. The gas distribution plate of claim 11 wherein said non-circular openings comprise:

- a) a plurality of elongated slots lying along lines which intersect a midpoint of said circular plate; and
- b) a plurality of arcuate slots lying in one or more circles coaxial with a midpoint of said circular plate; wherein each of said elongated slots crosses at least one of said arcuate slots.

16. The gas distribution plate of claim 11 wherein said non-circular openings comprise a plurality of crossed elongated slots.

17. A generally circular gas distribution plate for a semiconductor processing apparatus having means for inhibiting arcing adjacent said plate during plasma processing comprising a symmetrical pattern of non-circular openings in said plate through which gas may flow into said processing apparatus, each of said non-circular openings in said plate having a width smaller than the minimum diameter of a circular hole, in a symmetrical pattern of circular holes, at which arcing will occur but larger than the maximum diameter of a circular hole, in a symmetrical pattern of such holes, at which a halogen-containing plasma will block such openings.

18. The gas distribution plate of claim 17 wherein at least a portion of said non-circular openings comprise arcuate slots coaxially arranged around a midpoint on a face of said plate.

19. A generally circular planar gas distribution plate for a semiconductor processing apparatus having means for inhibiting arcing adjacent said plate during plasma processing comprising a symmetrical pattern of non-metallic electrically conductive members arranged on a face of said plate adjacent the periphery, each of said conductive members electrically connected to metallic portions of said plate.

20. A generally circular planar gas distribution plate for a semiconductor plasma processing apparatus to permit the flow of process gas into said processing apparatus while

inhibiting arcing adjacent said plate during said plasma processing which comprises symmetrical pattern of non-circular openings in said plate, at least a portion of which said openings comprise elongated arcuate slots having a major axis generally perpendicular to a line intersecting a midpoint on a face of said circular plate, and sidewalls of said arcuate slots parallel to said major axis are slanted toward said midpoint of said plate.

21. The gas distribution plate of claim 20 wherein said sidewalls of said elongated arcuate slots are slanted toward said midpoint at an angle, with respect to said face of said plate, ranging from about 30° to less than 90°.

22. A generally circular planar gas distribution plate for a semiconductor plasma processing apparatus to permit the flow of process gas into said processing apparatus while inhibiting arcing adjacent said plate during said plasma processing which comprises a symmetrical pattern of non-circular openings in said plate, comprising:

- a) first elongated slots comprising arcuate slots lying in circles coaxial to a midpoint on a face of said circular plate and having a major axis generally perpendicular to a line intersecting said midpoint on said face of said circular plate; and
- b) second elongated slots having a major axis intersecting said midpoint on said face of said circular plate, each of said second elongated slots intersecting at least one of said first elongated slots;

wherein said sidewalls of said first elongated arcuate slots parallel to said major axis of said first slots are slanted toward said midpoint of said face on said plate.

23. The gas distribution plate of claim 22 wherein said elongated arcuate slots are arranged in circles coaxial to said midpoint of said face of said plate.

24. The generally circular planar gas distribution plate for a semiconductor plasma processing apparatus of claim 23 wherein said non-circular openings comprising elongated slots have a first dimension smaller than about 762 μm (30 mils) to inhibit arcing; and a second dimension larger than said first dimension.

25. The gas distribution plate of claim 24 wherein sidewalls of said arcuate slots parallel to a major axis of said arcuate slots are slanted toward a midpoint on a face of said plate.

26. A generally circular planar gas distribution plate for a semiconductor plasma processing apparatus to permit the flow of process gas into said processing apparatus while inhibiting arcing adjacent said plate during said plasma processing which comprises:

- a) a symmetrical pattern of non-circular openings in said plate; and
- b) conductive structure on a face of said plate to inhibit arcing on said face of said plate.

27. The gas distribution plate of claim 26 wherein said conductive structure comprise non-metallic means generally symmetrically arranged adjacent the periphery of said circular plate.

28. A generally circular planar gas distribution plate for a semiconductor processing apparatus having structure for inhibiting arcing adjacent said plate during plasma processing comprising a symmetrical pattern of elongated slots in said plate through which gas may flow into said processing apparatus, each of said elongated slots having a major axis and a minor axis smaller than said major axis, said minor axis having a length:

- a) smaller than the diameter at which arcing will occur with circular openings; and
- b) larger than the diameter at which a halogen-containing plasma will block said circular openings;

said elongated slots further comprising:

- a) first elongated slots having a major axis parallel to a line intersecting a midpoint of said circular plate; and
- b) second elongated slots having a major axis perpendicular to said line intersecting said midpoint of said circular plate; and
- c) each of said first elongated slots intersects at least one of said second elongated slots.

* * * * *



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United States Patent [19]

Cherukuri et al.

[11] **Patent Number:** 5,603,351[45] **Date of Patent:** Feb. 18, 1997[54] **METHOD AND SYSTEM FOR INHIBITING CROSS-CONTAMINATION IN FLUIDS OF COMBINATORIAL CHEMISTRY DEVICE**

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[22] **Filed:** Jun. 7, 1995

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[52] **U.S. Cl.** 137/597; 204/269

[58] **Field of Search** 137/597, 551, 137/487.5; 204/269; 417/413.2, 413.3

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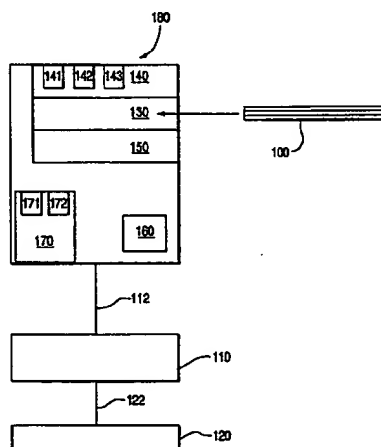
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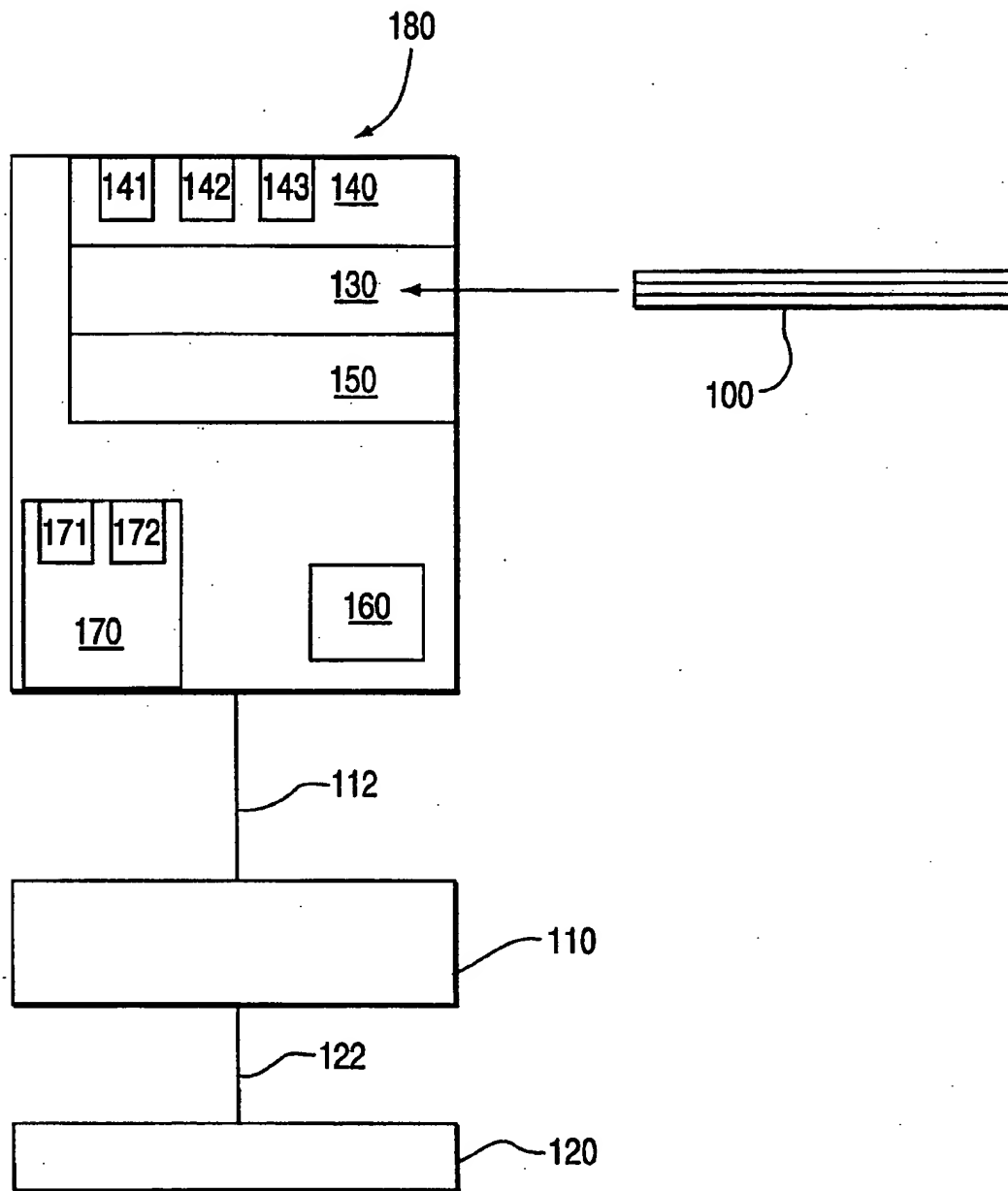
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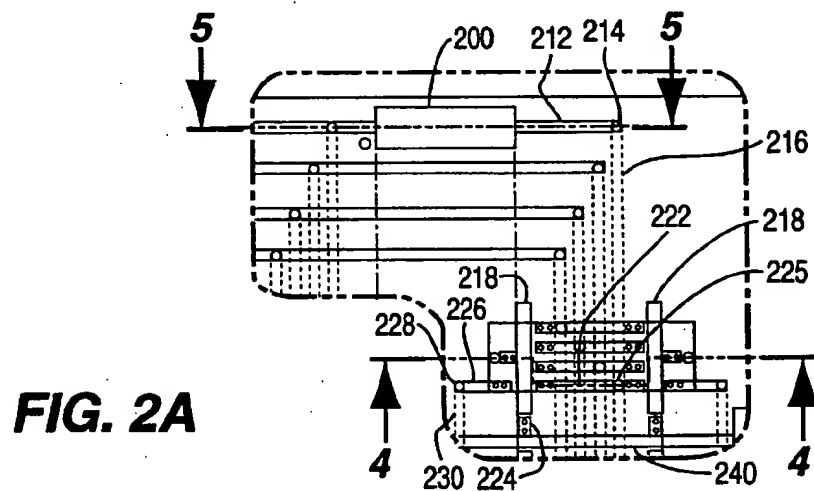
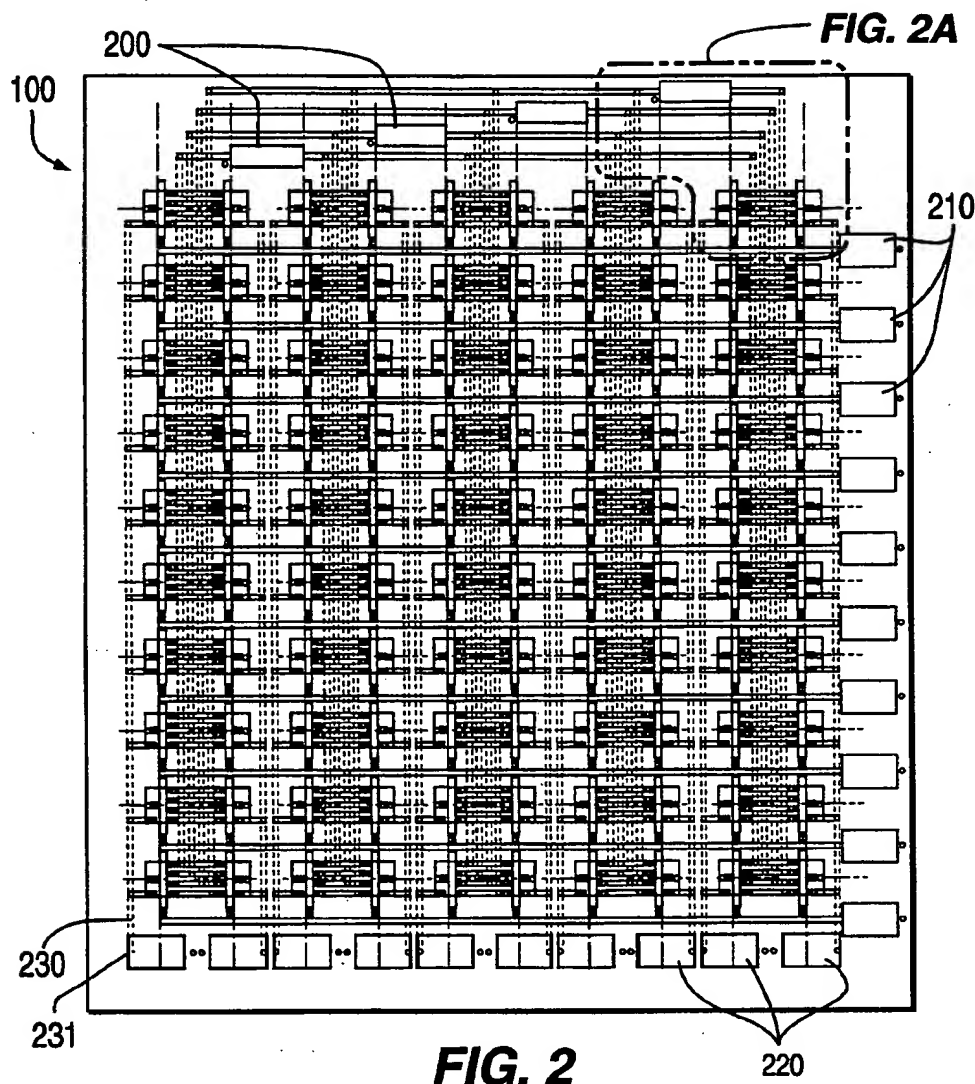
[57] **ABSTRACT**

A system and method for accomplishing a plurality of combinatorial processes in parallel comprising a microelectronic and fluidic array (device array) having micron-sized reservoirs, connecting microchannels and reaction cells etched into a substrate. The device array is supported by a station which serves to interface and perform electro-optic measurements of material in the reaction cells of the device array. The device array incorporates a modular configuration with three distinct layers or plates. The device array comprises a top feedthru plate, a center distribution plate and a bottom cell plate. The three plates are stacked vertically and coupled together to form a liquid-tight seal. Reservoirs, microchannels and reactions cells are controllably etched onto the plates using traditional semiconductor fabrication techniques. The top feedthru plate serves as a cover for the device array and contains apertures selectively positioned above the reservoirs located in the center distribution plate. The center distribution plate comprises a plurality of micron sized reservoirs, microchannels, reservoir feeds, cell feeds and overflow feeds for the distribution of reagent fluids to the reaction cells located in the bottom cell plate. The detachable bottom cell plate serves as a microlaboratory tray of reaction cells. Once the proper reagents or other materials are introduced into the reaction cells, the bottom cell plate is decoupled from the device array and removed for incubation or analysis.

34 Claims, 7 Drawing Sheets



**FIG. 1**



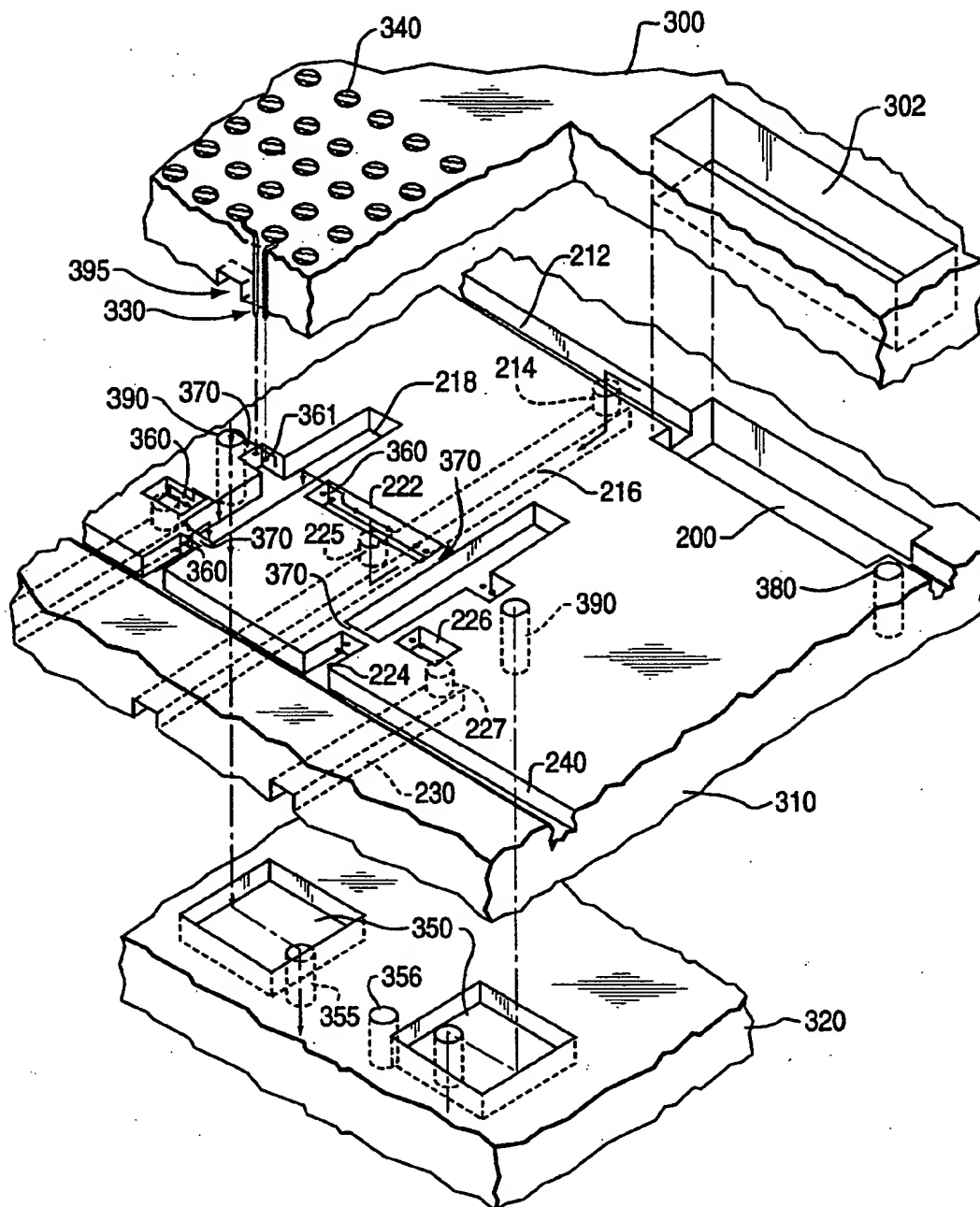
**FIG. 3**

FIG. 4

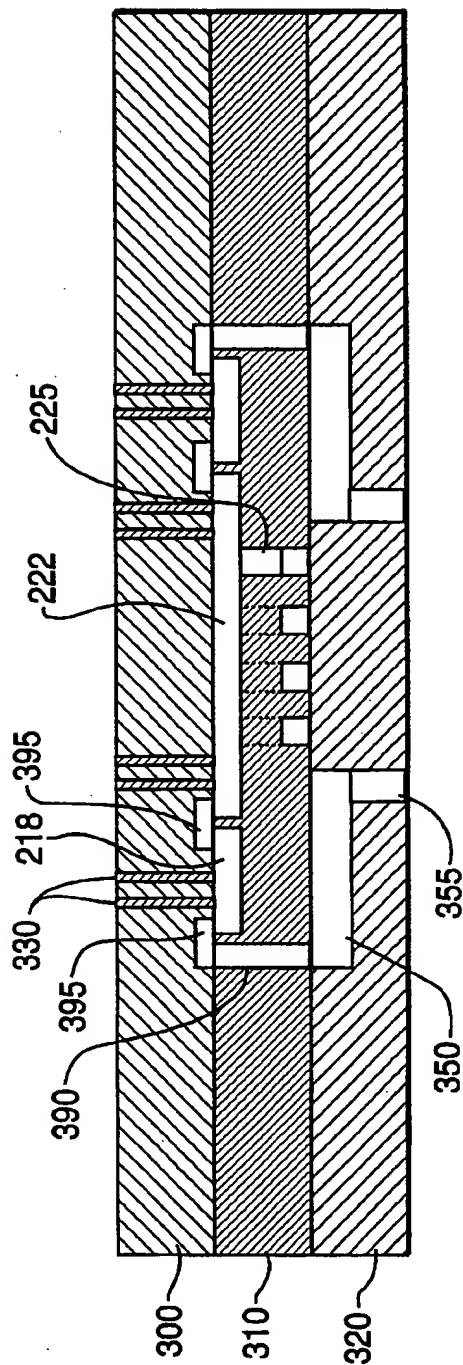
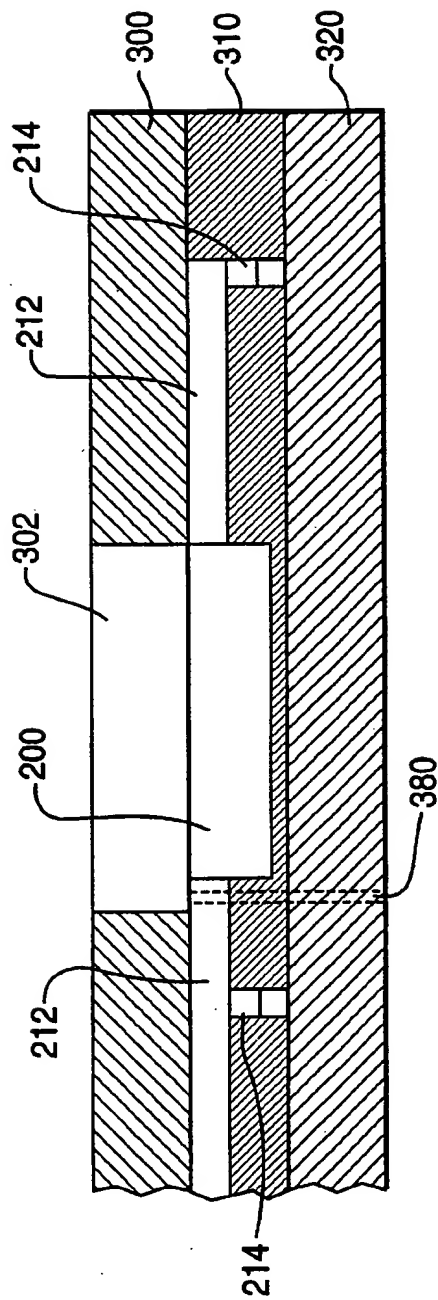


FIG. 5



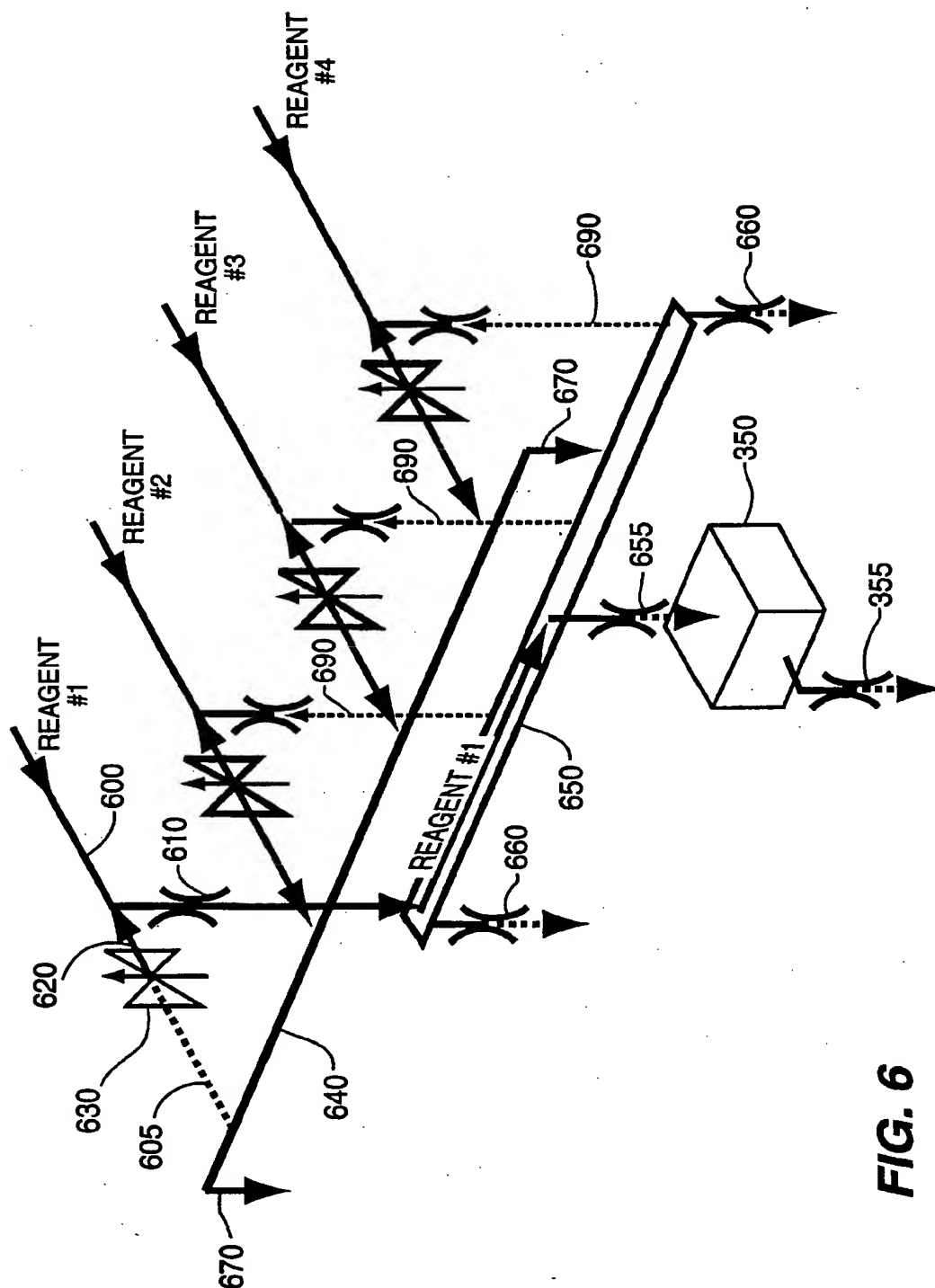
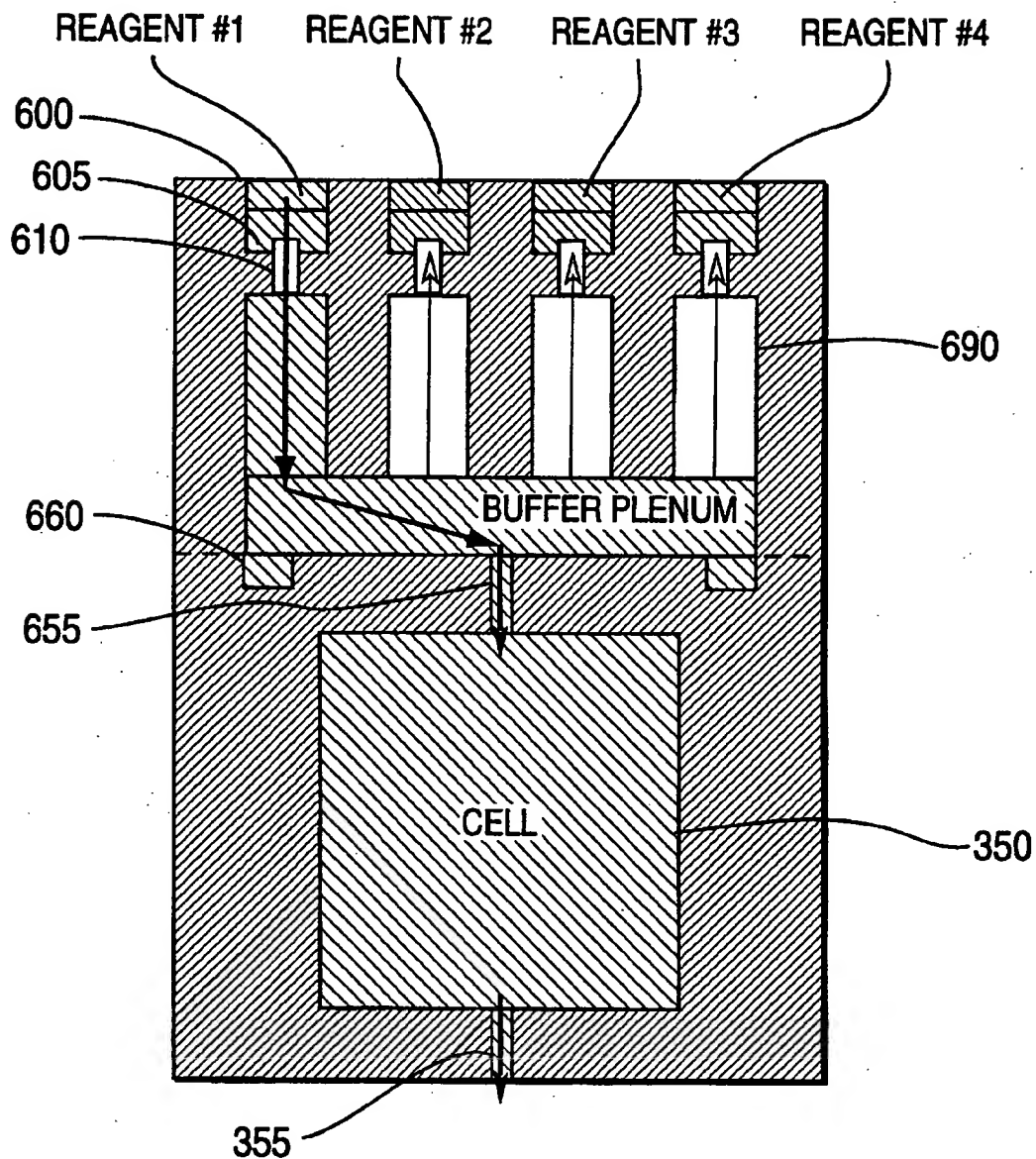


FIG. 6

**FIG. 7**

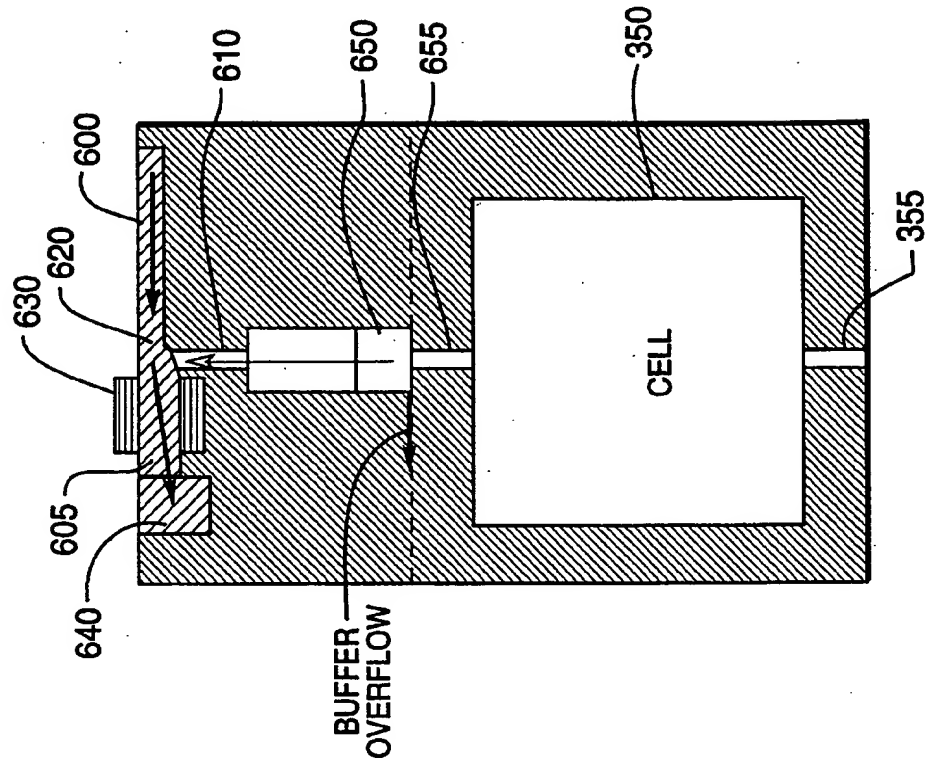


FIG. 8B

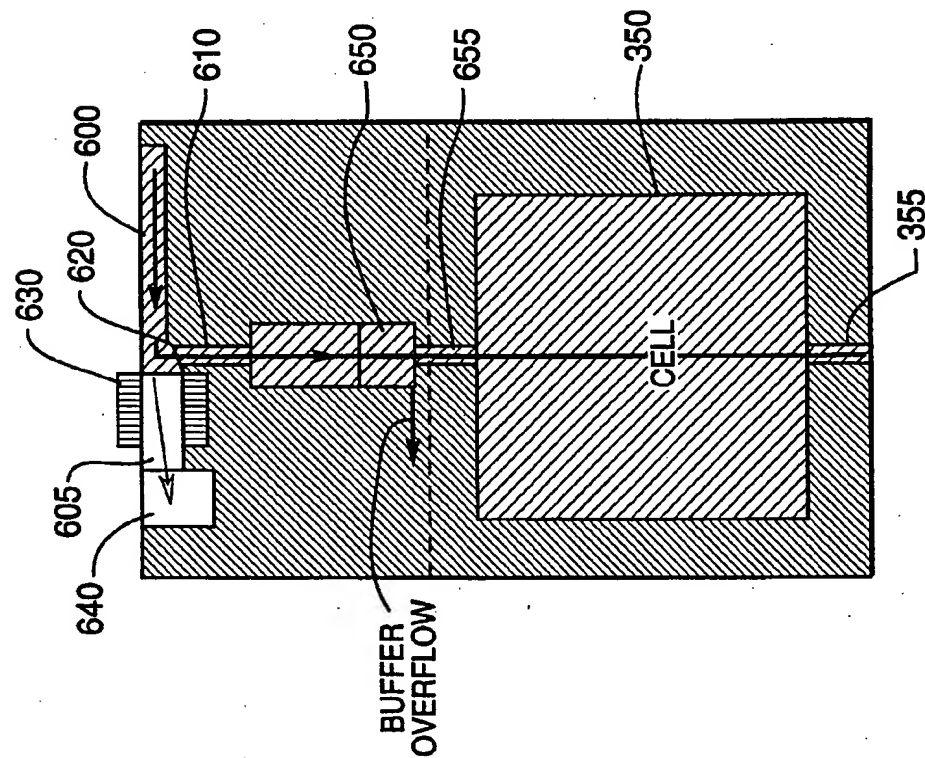


FIG. 8A

METHOD AND SYSTEM FOR INHIBITING CROSS-CONTAMINATION IN FLUIDS OF COMBINATORIAL CHEMISTRY DEVICE

The present invention relates to a method and system for accomplishing various combinatorial processes, including syntheses, screening and chemical diagnostic assays. More particularly, this invention relates to a system and method that incorporates a layered array for inhibiting cross-contamination of reagent fluids used in such combinatorial processes.

BACKGROUND OF THE INVENTION

Traditional methods in the field of combinatorial chemistry for making a homologous series of compounds or testing of new potential drug compounds were often slow and tedious. The underlying reason is that each member of the series or each potential drug compound must be created individually and tested individually. During this testing stage, it is common that the exact composition and/or behavior of a compound or new potential drug is unknown. In order to discover the proper composition of a compound or to observe the behavior of a new potential drug, a multitude of experiments must be conducted. For example, a plurality of potential drug compounds is tested by using an agent to test a plurality of materials that may differ only by a single amino acid or nucleotide base, or have a different sequence of amino acids or nucleotides. Furthermore, these experiments may investigate the effectiveness of the compound in different concentrations or its reaction to other reagents. This process for discovering and developing compounds or a new potential drug by combinatorial chemistry is labor intensive and costly.

Traditionally, these experiments are conducted by manually injecting reagent fluids or other agents into a multitude of vials. Each vial is filled manually by a laboratory technician. The solution within each vial may differ only slightly from an adjoining vial so that permutations of the solution are investigated simultaneously. Generally, a receptor having a fluorescent tag is introduced to each vial and the solution is incubated with the receptor. When a proper reaction is obtained where the receptor reacts with the solution, the result can be detected optically by observing the site of the fluorescent tag. The fluorescent data is transmitted to a computer which identifies the compound reacted and the degree of the reaction. Thus, combinatorial chemistry allows screening of thousands of compounds for the desired activity.

Recently, the process has been improved to some degree with the introduction of robotics into the field. Robotic arms are employed to automate the process of depositing materials into the multitude of vials. This improvement relieves the laboratory technician from a tedious task and increases the efficiency and accuracy of the process. A robotic arm is able to more accurately deposit a precise amount of material repeatedly into different vials.

However, the process continues to face problems in the area of cost and space. With thousands of compounds being tested and in some cases incubated over a period of time, the process requires a large quantity of space to house the multitude of trays of vials. In addition, these vials are generally large and cumbersome to handle.

Furthermore, the process generally consumes a large quantity of reagents for testing thousands of compounds. These reagents and other materials used in the process are

often very expensive or difficult to obtain. Thus, to reduce the cost and increase the efficiency of the process, it is necessary to replace the vials with other smaller reaction cells. By reducing the size of the reaction cell, the process consumes a smaller quantity of reagents. In addition, a proper control and delivery system is necessary for regulating and distributing minute amount of reagents to the reaction cells.

Recently, there are developments where traditional semiconductor techniques are combined with the synthesis of various compounds having potential biological activity. For example, a semiconductor or dielectric substrate is coated with a biologic precursor having such amino groups with a light-sensitive protective chemical. A series of masks are placed over the substrate with each mask having an opening. By introducing photosensitive amino acid through the openings, the reaction creates a particular compound that can be detected optically.

However, the synthesis of each reaction is not always complete and the process may need additional layers of mask for introducing new agents. Creating new masks is a complex and expensive process. In addition, the process of aligning a plurality of masks and forming openings in the mask in sequence requires careful alignment and is time consuming.

Nevertheless, the advantages in terms of size and efficiency of traditional semiconductor techniques are extremely attractive. Specifically, through the use of microchannels, the process of combinatorial chemistry is effectively conducted on a microcell scale. This approach addresses the problems of size and cost attributed to the traditional combinatorial process.

Therefore, a need exists in the art for a system and method that incorporates a microelectronic and fluidic array for accomplishing the process of combinatorial chemistry.

SUMMARY OF THE INVENTION

The system of the present invention comprises a microelectronic and fluidic array (device array) having micron sized reservoirs, connecting microchannels and reaction cells etched into a substrate. The device array is supported by a station which serves to interface and perform electrooptic measurements of material in the reaction cells of the device array. The station also controls the fluid flow of reagents to the reaction cells.

The device array incorporates a modular configuration with three distinct layers or plates. The device array comprises a top feedthru plate, a center distribution plate and a bottom cell plate. The three plates are stacked vertically and coupled together to form a liquid-tight seal. The top feedthru plate is bonded or fused to the center distribution plate, while the center distribution plate is detachably coupled to the bottom cell plate. The plates can be made from glass, fused silica, quartz or a silicon wafer. Reservoirs, microchannels and reaction cells are controllably etched onto the plates using traditional semiconductor fabrication techniques with a suitable chemical or laser etchant.

The top feedthru plate serves as a cover for the device array and contains apertures selectively positioned above the reservoirs located in the center distribution plate. These apertures provide the necessary openings for a loading module to fill the reservoirs with a plurality of reagents or other materials. The top feedthru plate further comprises a plurality of micropump electrodes that extend completely through the top feedthru plate. The micropump electrodes

are coupled to a plurality of electrical contacts on one end and are geometrically shaped to act as electrofluidic pumps on the other end. These miniature pumps (micropumps) are activated by selectively applying a voltage source to the electrical contacts located on the top surface of the top feedthru plate.

The center distribution plate comprises a plurality of micron-sized reservoirs, microchannels, reservoir feeds, cell feeds and overflow feeds, which are selectively etched on both sides (top and bottom) of the center distribution plate. These channels and reservoirs form a grid delivery system where reservoirs are grouped into column reservoirs, row reservoirs and matrix reservoirs. Column reservoirs are coupled to microchannels that deliver reagents to a location vertical from the column reservoirs, while row reservoirs are coupled to microchannels that deliver reagents to a location horizontal from the row reservoirs. Finally, matrix reservoirs are coupled to microchannels that deliver reagents to a location both vertical and horizontal from the matrix reservoirs.

Thus, the center distribution plate is defined into a plurality of sectors in a grid configuration. Each sector on the center distribution plate is directly positioned above a reaction cell located on the bottom cell plate. The reagents channeled to a sector from the different reservoirs are prohibited from entering the cell feed by a plurality of dams. By activating the miniature pumps, selected reagents are drawn over the dams from the microchannels and deposited into the reaction cells located in the bottom cell plate via the cell feeds.

The detachable bottom cell plate comprises a plurality of micron-sized reaction cells and drain feeds. The bottom cell plate effectively serves as a microlaboratory tray of reaction cells replacing the tray of vials used in the traditional process of combinatorial chemistry. Once the proper reagents or other materials are introduced into the reaction cells, the bottom cell plate is decoupled from the device array and removed for incubation or analysis. Generally, the bottom cell plate is analyzed under a detector, such as a fluorescence detector, to screen for a desired reaction.

Finally, the device array is supported by a laboratory station. The station comprises a computer, a detector module, an interface module and a loading module. The computer is programmed to give instructions to the device array and to record test results obtained therefrom. The interface module controlled by the computer is coupled to the top feedthru plate to selectively activate miniature pumps within the device array. The detector module serves to determine whether a desired reaction has occurred, while the loading module supplies the necessary reagents and other materials to conduct the experiments within the device array.

In one embodiment of the present invention, the center distribution plate incorporates a continuous flow configuration as opposed to an interrupted flow configuration as disclosed above. The continuous flow configuration incorporates a steady flow of reagents within the microchannels. The flow of the reagents in the microchannels is directed toward a drain away from the reaction cells. Contemporaneously, the reagents are also coupled to a plurality of constricted secondary buffer feeds which permit the reagents to flow into a buffer plenum. The buffer plenum is coupled to the reaction cells. A reagent fluid is selected by activating an electrically operated transducer or microgate to stop or inhibit the flow of the reagent into the drain, thereby forcing the reagent to flow into the secondary buffer feed and into the reaction cell. The volume of the selected reagent within

the buffer plenum and the negative pressure tend to isolate other reagents from entering the reaction cell.

BRIEF DESCRIPTION OF THE DRAWINGS

The teachings of the present invention can be readily understood by considering the following detailed description in conjunction with the accompanying drawings, in which:

FIG. 1 illustrates the system of the present invention adapted for performing the processes of combinatorial chemistry;

FIG. 2 illustrates the microlaboratory device array of the present invention;

FIG. 2A is a detailed section view of the microlaboratory device array shown in FIG. 2;

FIG. 3 illustrates an exploded perspective view of a section of the microlaboratory device array of the present invention;

FIG. 4 illustrates a sectional view of the microlaboratory device array of the present invention taken along line 44 of FIG. 2;

FIG. 5 illustrates a sectional view of the microlaboratory device array of the present invention taken along line 55 of FIG. 2;

FIG. 6 illustrates another embodiment of the present invention with a continuous flow configuration;

FIG. 7 illustrates the sectional front view of the present invention with a continuous flow configuration;

FIG. 8A illustrates the sectional side view of the present invention with a continuous flow configuration where the microgate is in the "closed" position; and

FIG. 8B illustrates the sectional side view of the present invention with a continuous flow configuration where the microgate is in the "open" position.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

DETAILED DESCRIPTION

FIG. 1 depicts the system of the present invention adapted for performing the processes of combinatorial chemistry. The system 50 comprises a microelectronic and fluidic array 100, computer 110, peripheral devices 120 and laboratory station 180. The computer 110 is electrically coupled to the laboratory station via line 112, where computer 110 controls the distribution of reagents to the appropriate reaction cells (not shown in FIG. 1) within the device array 100. Computer 110 is also programmed to record and analyze the test results obtained from the device array 100.

Peripheral devices 120 such as a modem or printer are electrically coupled to the computer 110 via line 122. These peripheral devices provide communication and reporting capabilities to the system.

Laboratory station 180 comprises a device array support 130, detector module 140, interface module 150, loading module 170 and waste fluids collectors 160. The laboratory station 180 in combination with computer 110 operates upon device array 100 to perform parallel testing of compounds.

Device array support 130 serves to receive and support device array 100 while reagents are deposited into the reservoirs of the device array. Suitable device array supports or substrate holders are commercially available.

Detector module 140 serves to detect the occurrence of a suitable reaction within the reaction cells of the device array 100. Detector module 140 comprises one or more light sources 141, an optical fiber 142 and one or more light detectors 143 such as a fluorescence detector. The optical fiber 142 is operative to transmit light from the light source 141 to the detector 143 through the reaction cells. Specifically, the detector module 140 measures the transmittance or absorbency of material in the reaction cells of the device array 100. The detector module 140 verifies the presence or absence of materials in the reaction cells and quantifies their amounts by transmitting the measurement data to the computer 110. Suitable lasers, photodetectors and fiber optic adapters for supporting the optical fiber are all commercially available. Furthermore, various fiber optic adapters may include a lens for efficient transfer of light from the light source into the optical fiber.

Interface module 150 serves as an interface for engaging the plurality of electrical contacts (shown in FIG. 3 and described below) located on the top surface of the device array 100. These electrical contacts provide the necessary electrical connections for operating a plurality of micropumps (not shown), which are employed to regulate the flow of reagents within the device array 100. The interface module 150 which is electrically connected between the computer 110 and device array 100, contains the necessary circuitry and connectors for selectively providing voltages to the electrical contacts of the micropumps in accordance with control signals from the computer 110. For a particular process, the computer 110 activates the micropumps in accordance with a predefined sequence of steps where different reagents are sequentially applied to the reaction cells. Thus, once the reagent reservoirs are filled, the process of loading the multitude of reaction cells with the proper reagent fluids is completely automated. This automation permits the preparation of a large array of reaction cells contemporaneously and reduces the cost and time required to obtain meaningful results.

Loading module 170 comprises pumps 171 and capillary tubings 172 for loading test materials and reagents onto the device array 100. The capillary tubings 172 have an inner diameter of about 200 microns and outer diameter of about 600-700 microns. For certain processes, the capillary tubings 172 are pretreated to eliminate surface adsorption of proteins and related bio-materials in a known manner such as methods disclosed by Cobb, "Electrophoretic Separations of Proteins in Capillaries with Hydrolytically Stable Surface Structures", Anal. Chem. 62, pp 2478-2483 (1990). The loading module 170 loads all materials onto the device array 100. The capillary tubings 172 are positioned over the apertures located on the top surface of the device array 100. Each aperture corresponds to a reagent reservoir located on the center distribution plate within the device array 100. Test materials are deposited into the reagent reservoirs through the force of gravity.

Optionally, pump 171 can be employed to pump the test materials into the reagent reservoirs. The external pump 171 can accurately deliver fluids in reproducible and controlled amounts. The 205U multi-channel cassette pump available from Watson-Marlow, Inc. is a suitable pump.

Waste fluids collectors 160 are housed in the laboratory station for the collection of waste fluids. Depending on a particular process, a plurality of reagent fluids is introduced into the reaction cells sequentially. This process may cause a sequential flushing of the reaction cells with different reagents where the expelled reagent fluids are collected into the waste fluids collectors 160. Furthermore, under a con-

tinuous flow configuration, reagent fluids flow continuously within the microchannels of the device array 100. The flow of the reagents in the microchannels is directed toward a drain away from the reaction cells. The excess reagents from the drain are collected into the waste fluid collectors 160.

FIG. 2 and FIG. 3 depict respectively a top view and an exploded cutout view of the device array 100 of the present invention, which is a microelectronic and fluidic array having micron sized reservoirs, connecting microchannels, feeds and reaction cells etched into a substrate. The device array 100 comprises three distinct layers or plates. Specifically, the device array 100 comprises a top feedthru plate 300, a center distribution plate 310 and a bottom cell plate 320. The three plates are stacked vertically and coupled together to form a liquid-tight seal. In the preferred embodiment of the present invention, the top feedthru plate 300 is bonded or fused to the center distribution plate 310 by thermal bonding or anodic bonding, while the center distribution plate 310 is detachably coupled to the bottom cell plate 320.

The plates can be made from glass, fused silica, quartz or a silicon wafer. The plates are suitably about 2 inches by 2 inches with a thickness of 1 millimeter. The reservoirs, microchannels and reactions cells are finely and controllably etched onto the plates using traditional semiconductor techniques with a suitable chemical or laser etchant. High quality glasses such as a high melting borosilicate glass or a fused silica are preferred for their ultraviolet transmission properties for processes that use light based technologies. In the preferred embodiment of the present invention, the top feedthru plate 300 is made from glass. The use of glass which serves as an insulator, permits the insertion of micropump electrodes in close proximity through the top feedthru plate 300. The use of other non-insulating material may cause a short between the densely packed micropump electrodes.

The center distribution plate 310 having a complex network of distribution microchannels, reservoirs and various feeds, is made preferably from silicon. The techniques for etching silicon are well known in the art which make silicon a preferred substrate for etching a complex distribution network. However, once etched, the silicon substrate is also pretreated to eliminate surface adsorption of proteins and related bio-materials.

The top feedthru plate 300 serves as a cover for the device array 100 and contains a plurality of apertures 302 selectively positioned above the reagent reservoirs 200, 210 and 220 located in the center distribution plate 310. The apertures are suitably about 500 microns by 3,000 microns and they extend completely through the top feedthru plate 300. These apertures 302 provide the necessary openings for the loading module 170 to fill the reagent reservoirs 200, 210 and 220 with a plurality of reagents or other materials.

The top feedthru plate 300 further comprises a plurality of micropump electrodes 330 that extend completely through the top feedthru plate 300. In the preferred embodiment of the present invention, the micropump electrodes 330 consist of electrical conduit (feedthru) of electroplated gold that terminates as a projection made of platinum. The length of the micropump electrodes 330 is about 50 microns with a diameter of about 50-100 microns. The micropump electrodes 330 are coupled between a plurality of electrical contacts 340 located on the top surface of the top feedthru plate 300 and a plurality of projections 331. Electrodes 330 serve as electrodes for miniaturized electrofluidic pumps 360 (location is shown only as two dots on the center

distribution plate 310). The movement of the fluids is accomplished by ionizing the fluids through application of a difference of potential. The electrical contacts 340 are engaged with the interface module 150, thereby permitting the computer 110 to control the activation of the miniature pumps 360 for loading the reaction cells 350 with a pre-defined sequence of reagent fluids. These miniature pumps 360 are activated by selectively applying a voltage to the electrical contacts 340 located on the top feedthru plate 300.

The miniaturized electrofluidic pumps 360 are based on electrokinetic pumps disclosed by Dasgupta et al., see "Electroosmosis: A Reliable Fluid Propulsion System for Flow Injection Analysis", *Anal. Chem.* 66, pp 1792-1798 (1994). Other suitable pumps are based on microelectromechanical systems (MEMS) such as reported by Shoji et al., "Fabrication of a Micropump for Integrated Chemical Analyzing Systems", *Electronics and Communications in Japan*, Part 2, 70, pp 52-59 (1989).

The center distribution plate 310 comprises a plurality of micron sized reservoirs 200, 210 and 220, microchannels 212, 216, 218, 222, 224, 226, 230 and 240, reservoir feeds 214, cell feeds 370 and overflow feeds 380, which are selectively etched on both sides (top and bottom) of the center distribution plate 310. The reagent reservoirs are located on the sides of the device array 100. The reservoirs are classified into matrix reservoirs 200, row reservoirs 210 and column reservoirs 220. Column reservoirs 220 are coupled to microchannels that deliver reagents to a location vertical from the column reservoirs, while row reservoirs 210 are coupled to microchannels that deliver reagents to a location horizontal from the row reservoirs. Finally, matrix reservoirs 200 are coupled to microchannels that deliver reagents to a location both vertical and horizontal from the matrix reservoirs. Although three (3) sets of reagent reservoirs 200, 210 and 220 are illustrated, those skilled in the art will realize that additional sets of reagent reservoirs can be incorporated into the device array.

The matrix reservoirs 200 are capable of providing reagent fluids to all reaction cells 350. Referring to FIG. 2 and FIG. 3, each matrix reservoir 200 is connected to a horizontal microchannel 212 which extends horizontally across the device array 100 (from a top perspective view). A plurality of reservoir feeds 214 is placed along the length of microchannel 212. Each reservoir feed 214 serves as a feedthru for connecting a horizontal microchannel 212 with a vertical microchannel 216 which extends vertically across the device array 100 (from a top perspective view). The vertical microchannel 216 is in turn coupled to a distribution microchannel 222 via distribution feed 225. Thus, the matrix reservoirs 200 are capable of providing reagents to all "sectors" on the center distribution plate 310. Each sector on the center distribution plate 310 is an area positioned directly above a reaction cell as illustrated by FIG. 3.

To illustrate, as a reagent fluid is deposited into matrix reservoir 200, the reagent fluid fills the reservoir 200 and overflows into horizontal microchannel 212. The reagent fluid is channeled downward into the vertical microchannel 216 via reservoir feed 214, which functions like a feedthru. Finally, as the reagent fluid completely fills the length of vertical microchannel 216, the reagent fluid swells upward into distribution microchannel 222 via distribution feed 225. The reagent fluid will only rise up to the top surface of the center distribution plate 310. The underlying reason is that the reagent fluid level is controlled by the overflow feeds 380 and by the physical contact of the top feedthru plate 300. As the reagent fluid completely fills all the distribution microchannels 222, the level of the fluid is stabilized by

draining excess fluids into overflow feeds 380. It should be noted that for simplicity, FIG. 3 depicts only one set of microchannel 216 and distribution microchannel 222. As illustrated in FIG. 2, there are actually four (4) sets (or more) of these microchannels.

The flow of reagent fluids from the row reservoirs 210 operates in a similar fashion. As a reagent fluid is deposited into row reservoir 210, the reagent fluid fills the reservoir and overflows into horizontal microchannel 240. The reagent fluid simply flows along the horizontal microchannel 240 and into microchannels 224. Finally, as the reagent fluid completely fills the length of microchannel 240, the reagent fluid also rises up to the top surface of the center distribution plate 310. Again, the overflow feeds 380 and the physical contact of the top feedthru plate 300 combine to control the reagent fluid level. As the reagent fluid completely fills all the distribution microchannels 224, the level of the fluid is stabilized by draining excess fluids into overflow feeds 380. One significant difference between the matrix reservoirs 200 and the row reservoirs 210 is that the row reservoirs are only capable of delivering its reagents to the reaction cells 350 that are situated horizontally from the row reservoirs. However, the matrix reservoirs 200 are capable of delivering its reagents to all reaction cells 350 within the device array 100.

The flow of reagent fluids from the column reservoirs 220 also operates in the same manner. As a reagent fluid is deposited into column reservoir 220, the reagent fluid fills the reservoir and overflows downwardly into vertical microchannel 230 via column feed 231, which functions like a drain. Finally, as the reagent fluid completely fills the length of the vertical microchannel 230, the reagent fluid swells upward into distribution microchannel 226 via distribution feed 227. Again, the same overflow scheme controls the reagent fluid level from the column reservoir 220. Similar to the row reservoirs, the column reservoirs are only capable of delivering its reagents to the reaction cells 350 that are situated vertically from the column reservoirs. This configuration of the various reservoirs permits a large array of parallel tests to be conducted simultaneously.

To illustrate, using a device array with x by y number of reaction cells, the matrix reservoirs, row reservoirs and column reservoirs may incorporate a flushing agent, reagent fluid A of different concentrations (A_1-A_x) and reagent fluid B of different concentrations (B_1-B_y) respectively. Each concentration of the reagents A and B is stored in a separate reservoir. The process starts by releasing the reagent fluids A_1-A_x from the row reservoirs into the reaction cells and then applying the flushing agent through the whole distribution system for cleansing purposes. Next, the process may release the reagent fluids B_1-B_y from the column reservoirs into the reaction cells. Under this illustrative example, all the possible permutations of combining different concentrations of reagent fluid A with different concentrations of reagent B are accomplished efficiently and contemporaneously in parallel in one single device array. Due to the small size of the device array 100, the amount of reagents consumed is on the order of nanoliters instead of liters.

Referring to FIGS. 2-5, the reagent fluid is prohibited from flowing into buffer channel 218 by a plurality of dams 370. The dams safeguard against seepage of unwanted reagents into the reaction cells 350 and also safeguard against cross contamination of different reagent fluids. A micropump 360 is positioned at the edge of each dam 370 where, upon activation, the micropump permits the reagent fluids to enter into buffer channel 218 through a flow sluice 395. A flow sluice which is etched on the bottom surface of the top feedthru plate 300 is provided for each dam 370.

Once the reagent fluid enters the buffer channel 218, another micropump 361 is activated to pump the reagent fluid into the reaction cell 350 via a cell feed 390. The buffer channel 218 effectively provides an additional safeguard against contamination of the reaction cell 350 with unwanted reagents. The buffer channel serves to dilute any seepage of unwanted reagents that may enter the buffer channel 218. During normal operation, the buffer channel 218 is filled with the desired reagent which is pumped into the buffer channel from one of the distribution microchannels 222, 224 or 226. Thus, there is a flow of reagent fluid from the desired distribution microchannel to the reaction cell 350 via the buffer channel 218. This positive flow effectively prevents the seepage of unwanted reagents from the remaining two distribution microchannels, which actually experience a slight negative pressure. In the event that unwanted reagents do enter the buffer channel 218, the impact of the contamination is reduced because the contamination is diluted with the desired reagents presently in the buffer channel 218.

To summarize, the center distribution plate 310 is defined into a plurality of sectors in a grid configuration. Each sector on the distribution plate is positioned directly above a reaction cell 350 located on the bottom cell plate 320. The reagents channeled to a sector from the different reservoirs 200, 210, and 220 are prohibited from entering the cell feed 390 by a plurality of dams 370. By activating the miniature pumps 360 and 361, selected reagents are drawn over the dams 370 from the distribution microchannels through the buffer channel and are deposited into the reaction cells 350 located on the bottom cell plate 320 via the cell feeds 390.

In the preferred embodiment of the present invention, the diameter of the various feeds are suitably about 100 microns. The depth of each feed depends upon the microchannels that are connected by such feed. The size of the microchannels is suitably about 150 microns in width and about 100 microns in depth. Depending on the application, the length of the microchannels varies from 500 microns to the full length of the device array 100.

The bottom cell plate 320 comprises a plurality of micron sized reaction cells 350 and drain feeds 355. In the preferred embodiment of the present invention, the bottom cell plate 320 comprises a total of one hundred (10 by 10) reaction cells 350. However, those skilled in the art will realize that the device array can incorporate any number of reaction cells by adjusting the size of the device array. The size of the reaction cell is suitably about 1,000 microns by 1,000 microns with a depth of about 250 microns. The bottom cell plate 320 effectively serves as a detachable microlaboratory tray of reaction cells 350 replacing the tray of vials used in the traditional process of combinatorial chemistry. Once the proper reagents or other materials are introduced into the reaction cells 350, the bottom cell plate 320 is decoupled from the device array 100 and removed for incubation or analysis. Generally, the bottom cell plate 320 is analyzed under a detector, such as a fluorescence detector, to screen for a desired reaction.

The drain feed 355 provides a drain for removing materials from the reaction cell 350 to the waste fluid collectors 160 of laboratory station 180. The drain feeds 355 is disposed on the bottom of the reaction cells 350. Alternatively, as shown in FIG. 3, the drain feeds 356 can be disposed along side of the reaction cell 350 as in the case of the overflow feeds 380 in relation to the reservoirs 200. Again, a flow sluice (not shown) which is etched on the bottom surface of the center feedthru plate 310 is provided over each dam separating the reaction cell and the drain feed, for allowing the reagent fluids to enter the drain feed

356. In this alternate configuration, solid materials such as catalyst beads (not shown) which are used to provide reaction surfaces, will not hinder the flow of waste fluids exiting the reaction cells 350.

FIG. 6 and FIG. 7 depict a second embodiment of the present invention, where the center distribution plate 310 incorporates a continuous flow configuration as opposed to an interrupted flow configuration as disclosed above. The continuous flow configuration incorporates a steady flow of reagents within the microchannels 600. The steady flow of the reagents in the microchannels 600 is directed toward a branch bypass microchannel 605 that leads to a common bypass channel 640 where the reagents are channeled into a drain 670 and away from the reaction cell 350. To enhance the flow of reagents toward the drains 670, each microchannel 600 incorporates an expansion section 620 where the microchannel 600 is widened to permit easy passage of reagent fluids. Contemporaneously, the reagents are also coupled to a constricted secondary buffer feed 610 which permits the reagents to flow into a buffer plenum 650. The buffer plenum 650 is coupled to the reaction cell 350 via a cell feed 655.

Furthermore, a transducer or microgate 630 (can also be a micropump 360 operated in reverse) is disposed along the expansion section 620. The microgate 630 is controlled in the same manner as the micropumps 360 as disclosed above. However, unlike the micropumps 360, the microgate 630 functions as a gate to selectively prohibit the flow of reagent fluids when the microgate is activated.

FIGS. 8A and 8B illustrate the operation and effect of the microgate 630. In FIG. 8A, the microgate 630 is in the "closed" position where the branch bypass microchannel 605 is blocked by the microgate 630. The reagent fluid is redirected into the constricted secondary buffer feed 610 and into the buffer plenum 650. The steady flow of reagent fluid is received by the reaction cell 350 and the buffer overflow drains 660. Thus, a reagent fluid is selected by activating the corresponding microgate 630 to stop or inhibit the flow of the reagent fluid into the common bypass 640, thereby forcing the reagent fluid to flow into the secondary buffer feed 610 and into the reaction cell 350. Again, the diluting effect of the selected reagent fluid within the buffer plenum 650 and the negative pressure (illustrated as 690 in FIG. 6 and 7) tend to isolate other reagents from entering the reaction cell 350. In fact, the negative pressure may cause the selected reagent fluid to flow into the microchannels 600 of other reagent fluids. However, this contamination is negligible because the steady flow of reagent fluids within the microchannels 600 will likely carry the contamination to the common bypass 640 due to the positive fluid flow.

Conversely, FIG. 8B depicts the microgate 630 in the "open" position where the branch bypass microchannel 605 is unrestricted by the microgate 630. The reagent fluids tend to flow in the direction of least resistance which is in the direction of the expansion section 620. The reagent fluids enter the common bypass 640 and are directed toward drains 670 away from the reaction cell 350. In fact, a slight negative pressure or zero pressure may exist at the secondary buffer feed 610 to prevent the contamination of the reaction cell by unwanted reagent fluids.

There has thus been shown and described a novel system and method that incorporates a layered array for inhibiting cross-contamination of reagent fluids used in the processes of combinatorial chemistry. Many changes, modifications, variations and other uses and applications of the subject invention will, however, become apparent to those skilled in the art after considering this specification and the accom-

panying drawings which disclose the embodiments thereof. All such changes, modifications, variations and other uses and applications which do not depart from the spirit and scope of the invention are deemed to be covered by the invention, which is to be limited only by the claims which follow.

What is claimed is:

1. An array for accomplishing various chemical processes through the use of fluids, the array comprising:

a plurality of reservoirs, microchannels and reaction cells disposed on a dielectric substrate, where fluids are selectively channeled from the plurality of reservoirs to the plurality of reaction cells through the plurality of microchannels;

a plurality of micropumps located in the array for pumping fluid through the microchannels; and

a plurality of dams located in the array, each for inhibiting the flow of fluid in one of the microchannels.

2. The array of claim 1, wherein, for each dam, the activation of a micropump in the array is effective to push the fluid past the dam.

3. The array of claim 1, wherein at least one of the dams is located so as to inhibit the flow of fluid from one microchannel to a channel connected to a reaction cell.

4. The array of claim 1, wherein microchannels are formed in the top surface of a first plate of dielectric substrate that is sealed to the bottom surface of a second plate of dielectric substrate, and wherein, for each dam, a conduit over the dam is formed in the bottom surface of the second plate.

5. The array of claim 1, wherein microchannels and reservoirs are formed in the top surface of a first plate of dielectric substrate that is sealed to the bottom surface of a second plate of dielectric substrate.

6. The array of claim 5, wherein the second plate has a plurality of apertures, each located above a reservoir, for transferring fluids into the reservoirs.

7. The array of claim 5, further comprising a third plate of dielectric substrate located underneath the first plate and defining the plurality of reaction cells.

8. The array of claim 5, wherein the second plate further comprises a plurality of electrical conduits extending through the second plate and wherein the array further comprises a plurality of micropumps connected to the plurality of electrical conduits.

9. The array of claim 8, wherein the micropumps each comprise two electrodes projecting from the electrical conduits.

10. The array of claim 9, wherein the electrodes have shaped termini.

11. The array of claim 5 wherein the first plate further comprises a buffer channel connected to a plurality microchannels via intervening dams, the buffer channel minimizing cross contamination of fluids.

12. The array of claim 1, wherein the dielectric substrate is glass.

13. A system for accomplishing various chemical processes through the use of fluids, the system comprising:

the array of claim 1, and

a control apparatus, electrically connected to the array, for controlling a flow of the fluids within the array.

14. An array for accomplishing various chemical processes through the use of fluids, the array comprising:

a plurality of reservoirs, microchannels and reaction cells disposed on a dielectric substrate, where fluids are selectively channeled from the plurality of reservoirs to

the plurality of reaction cells through the plurality of microchannels, wherein the reservoirs and microchannels are formed in a first plate of dielectric substrate, the top surface of which is sealed to the bottom surface of a second plate of dielectric substrate;

a plurality of electrical conduits extending through the second plate; and

a plurality of micropumps connected to the electrical conduits.

15. The array of claim 14, further comprising a plurality of dams located in the array, each for inhibiting the flow of fluid in one of the microchannels.

16. The array of claim 15, wherein, for each dam, the activation of a micropump in the array is effective to push the fluid past the dam.

17. The array of claim 15, wherein at least one of the dams is located so as to inhibit the flow of fluid from one microchannel to a channel connected to a reaction cell.

18. The array of claim 15, wherein, for each dam, a conduit over the dam is formed in the bottom surface of the second plate.

19. An array for accomplishing various chemical processes through the use of fluids, the array comprising:

a plurality of microchannels and reaction cells disposed on a dielectric substrate, wherein the microchannels are formed in a first plate of dielectric substrate, the top surface of which is sealed to the bottom surface of a second plate of dielectric substrate,

wherein the microchannels comprise a plurality of continuous flow channels each designed to maintain a continuous flow of a fluid which can be delivered to a plurality of reaction cells and a bypass channel connected to the plurality of continuous flow channels for accepting and draining the fluid from the continuous flow microchannels that is not delivered to a reaction cell.

20. The array of claim 19, further comprising a buffer plenum for minimizing cross contamination of fluids.

21. The array of claim 20, wherein the first plate further comprises, for each of a plurality of continuous flow channels, a first channel for connecting that continuous flow microchannel channel to the buffer plenum.

22. The array of claim 19, wherein the second plate further comprises a plurality of electrical conduits extending through the second plate and wherein the array further comprises a plurality of micropumps, which are connected to the plurality of electrical conduits, for regulating the flow of the fluids.

23. A system for accomplishing various chemical processes through the use of fluids, the system comprising:

the array of claim 22,

a control apparatus, electrically connected to the array, for controlling a flow of the fluids within the array, and an interface module coupled to the array for electrically connecting the array to the control apparatus.

24. The array of claim 20, wherein the continuous flow channels each further comprise an expansion section for enhancing passage of the fluids.

25. An array for accomplishing various chemical processes through the use of fluids, the array comprising:

a plurality of reservoirs, microchannels and reaction cells disposed on a dielectric substrate, where fluids are selectively channeled from the plurality of reservoirs to the plurality of reaction cells through the plurality of microchannels, wherein the reservoirs and microchannels are formed in a first plate of dielectric substrate,

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the top surface of which is sealed to the bottom surface of a second plate of dielectric substrate;
 a plurality of electrical conduits extending through the second plate; and
 a plurality of micropumps each comprising two electrodes, which electrodes project from the electrical conduits.

26. The array of claim 25, further comprising a plurality of dams, each for inhibiting the flow of fluid in one of the microchannels.

27. The array of claim 26, wherein, for each dam, the activation of a micropump in the array is effective to push the fluid past the dam.

28. The array of claim 26, wherein at least one of the dams is located so as to inhibit the flow of fluid from one microchannel to a channel connected to a reaction cell.

29. The array of claim 26, wherein microchannels are formed in the top surface of a first plate of dielectric substrate that is sealed to the bottom surface of a second

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plate of dielectric substrate, and wherein, for each dam, a conduit over the dam is formed in the bottom surface of the second plate.

30. The array of claim 25, wherein microchannels and reservoirs are formed in the top surface of the first plate of dielectric substrate that is sealed to the bottom surface of the second plate of dielectric substrate.

31. The array of claim 30, wherein the second plate has a plurality of apertures, each located above a reservoir, for transferring fluids into the reservoirs.

32. The array of claim 25, wherein the electrodes have shaped termini.

33. The array of claim 25, wherein the dielectric substrate is glass.

34. The array of claim 25, wherein the dielectric substrate is high melting borosilicate glass or fused silica.

* * * * *

United States Patent [19]**DeDontney et al.**[11] **Patent Number:** **5,683,516**[45] **Date of Patent:** **Nov. 4, 1997**[54] **SINGLE BODY INJECTOR AND METHOD FOR DELIVERING GASES TO A SURFACE**[75] **Inventors:** **Jay B. DeDontney; Nicholas M. Gralenski; Adam Q. Miller, all of Santa Cruz, Calif.**[73] **Assignee:** **Watkins-Johnson Co., Palo Alto, Calif.**[21] **Appl. No.:** **621,772**[22] **Filed:** **Mar. 22, 1996****Related U.S. Application Data**[63] **Continuation of Ser. No. 276,815, Jul. 18, 1994, abandoned.**[51] **Int. Cl.⁶** **C23C 16/00**[52] **U.S. Cl.** **118/718; 118/715**[58] **Field of Search** **118/715, 718, 118/725; 156/345**[56] **References Cited****U.S. PATENT DOCUMENTS**

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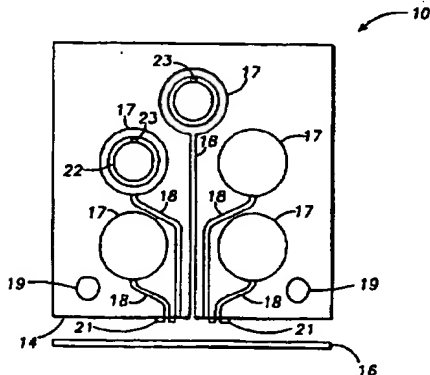
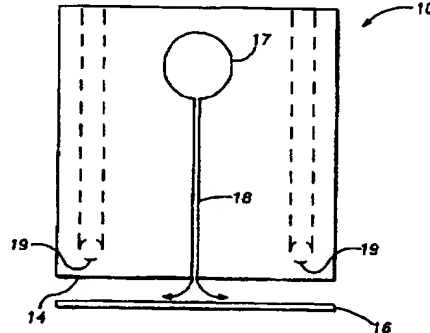
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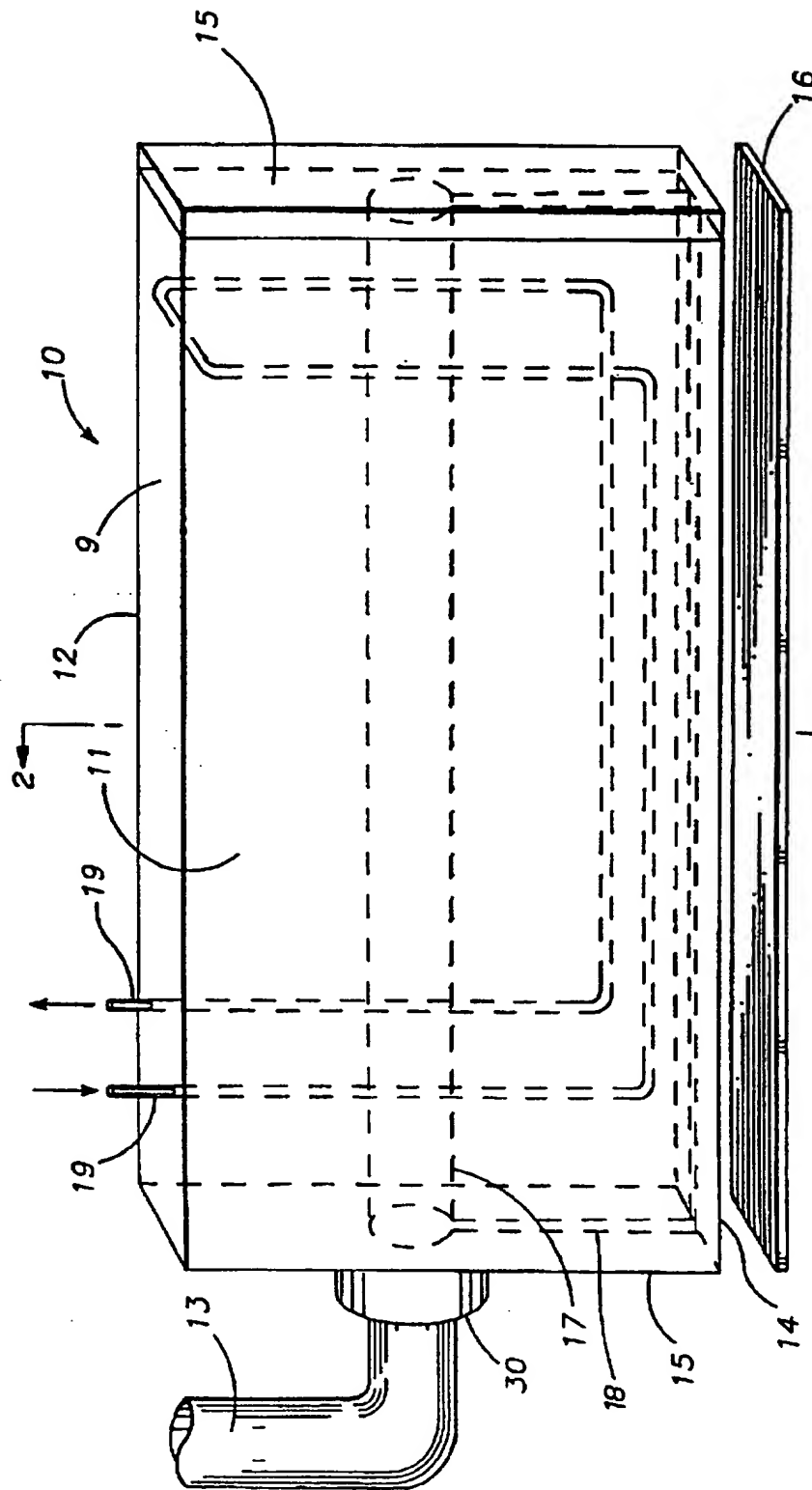
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Primary Examiner—R. Bruce Breneman*Assistant Examiner*—Jeffrie R. Lund*Attorney, Agent, or Firm*—Flehr Hobbach Test Albritton & Herbert LLP[57] **ABSTRACT**

A single body injector for delivering gases to a surface. The injector includes a single elongated block with one or more passages formed in the block and communicating with a gas delivery surface via thin channels which extend between the passages and the gas delivery surface. Metering tubes may be placed in the passages to control the profile of the gases delivered.

26 Claims, 5 Drawing Sheets



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FIG. - 1

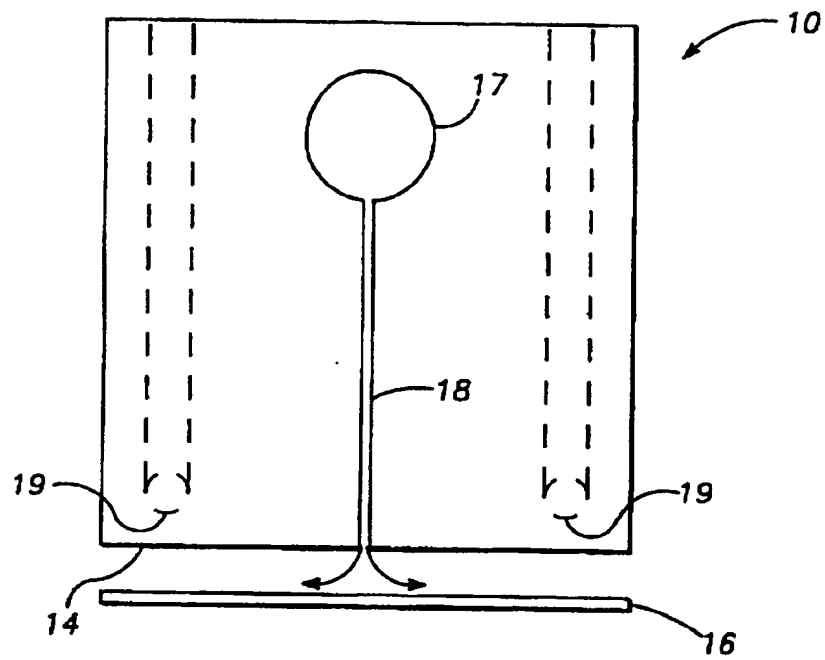


FIG. -2

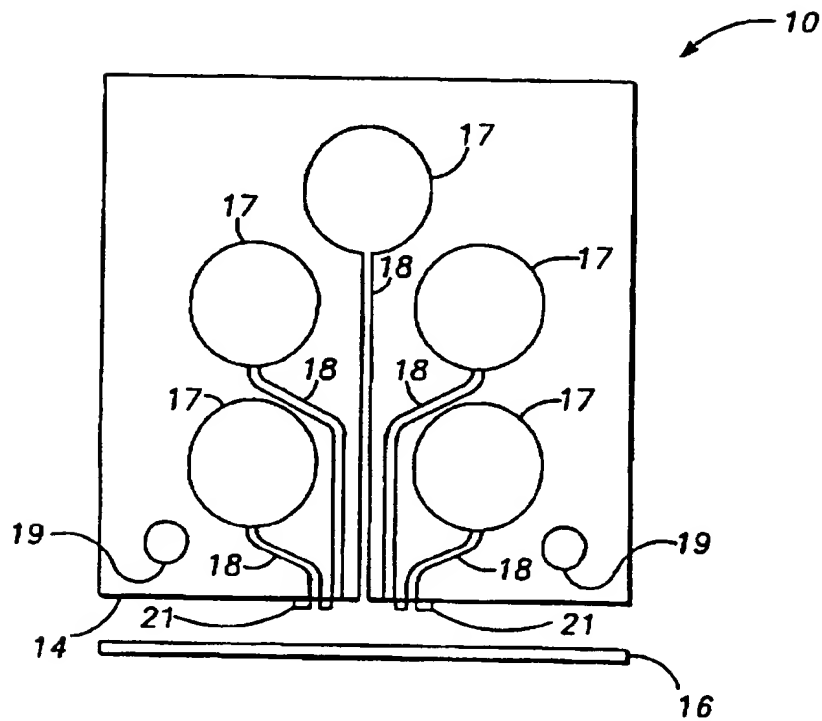


FIG. -3

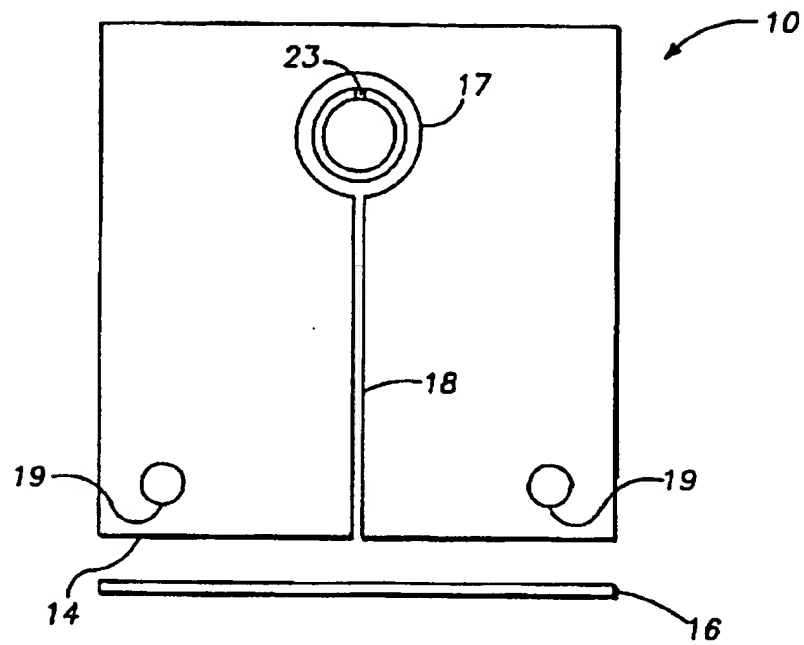


FIG. -4

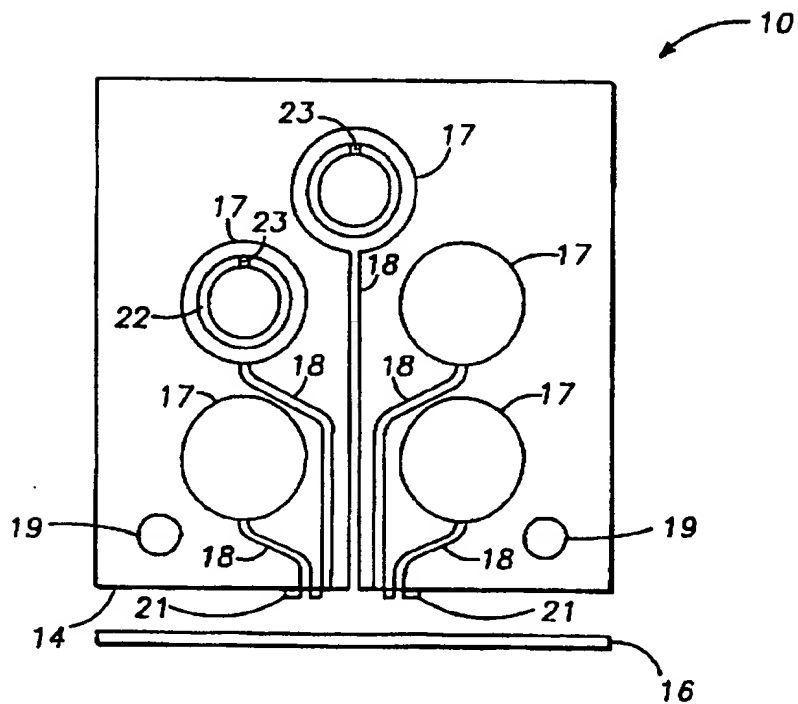


FIG. -5

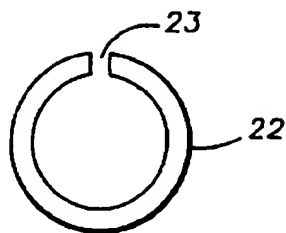


FIG. -6

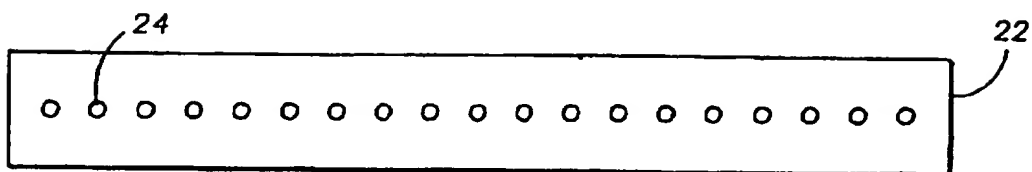


FIG. -7

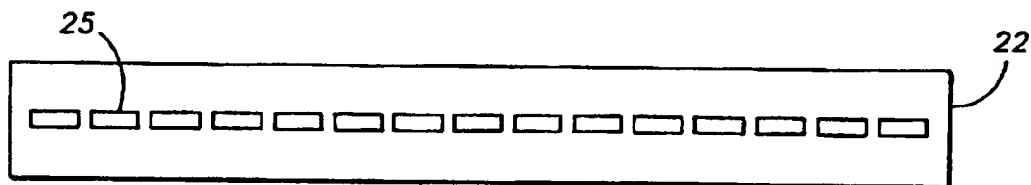


FIG. -8

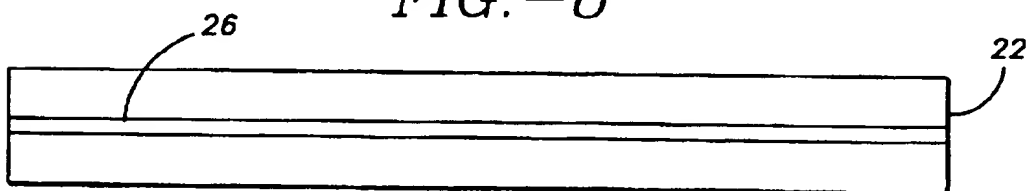


FIG. -9

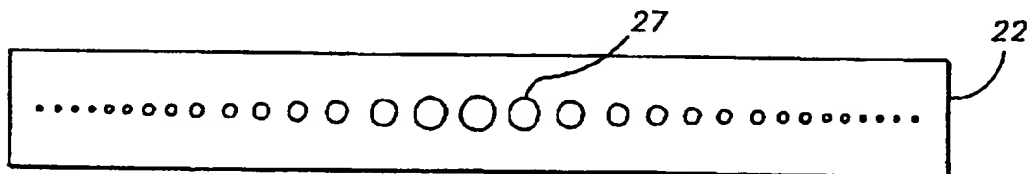


FIG. -10

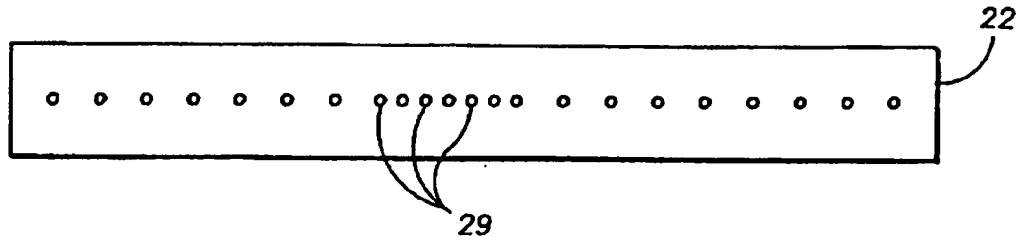


FIG. - 11

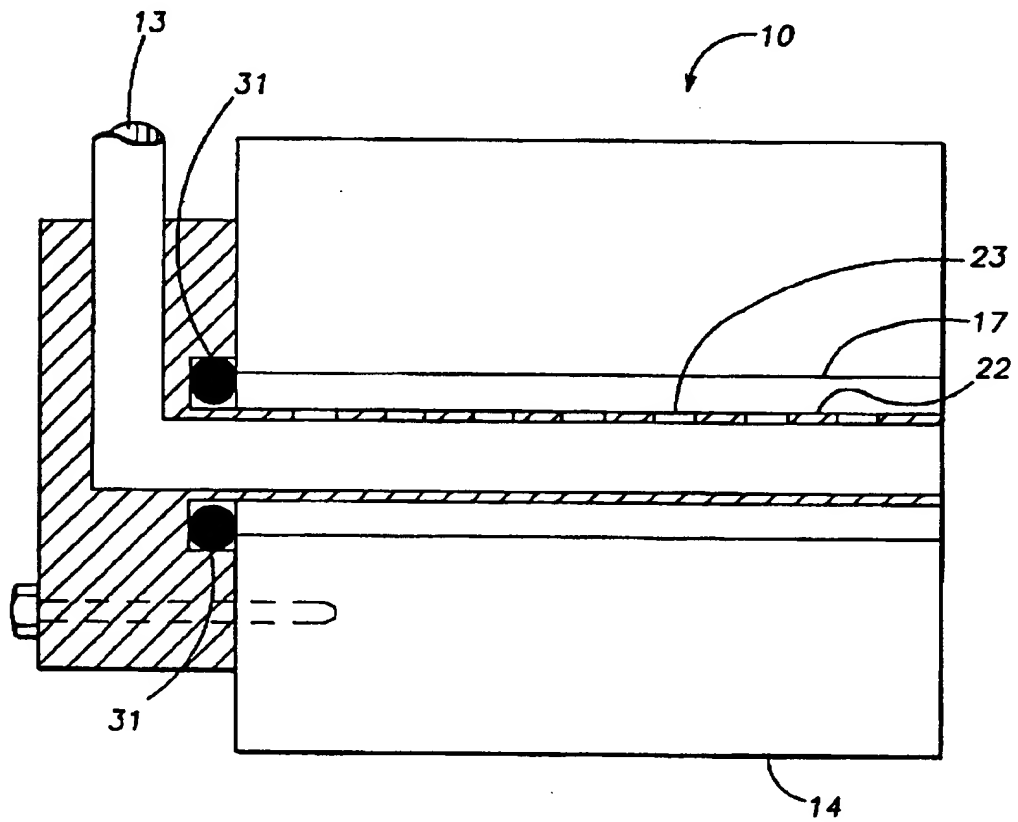


FIG. - 12

SINGLE BODY INJECTOR AND METHOD FOR DELIVERING GASES TO A SURFACE

This is a continuation of application Ser. No. 08/276,815 filed Jul. 18, 1994 now abandoned.

BRIEF DESCRIPTION OF THE INVENTION

The present invention relates to an injector for delivering gaseous chemicals to a surface. More particularly, the invention relates to an improved injector for delivering gaseous chemicals to a surface for depositing uniform films or layers on the surface by chemical vapor deposition (CVD).

BACKGROUND OF THE INVENTION

Chemical vapor deposition (CVD) is a critical component in semiconductor manufacturing. CVD occurs when a stable compound is formed by a thermal reaction or decomposition of certain gaseous chemicals and such compounds are deposited on a surface. CVD systems come in many forms. One apparatus for such a process comprises a conveyORIZED atmospheric pressure CVD (APCVD) system which is described in U.S. Pat. No. 4,834,020 and is owned by assignee. This patent is incorporated herein by reference.

One critical component of CVD systems is the injector utilized for delivering gaseous chemicals to the surface. The gases must be distributed over the substrate, so that the gases react and deposit an acceptable film at the surface of the substrate. A function of the injector is to distribute the gases to a desired location in a controlled manner. Controlled distribution of the gases maximizes the chance of complete, efficient and homogeneous reaction of the gases, in part by minimizing pre-mixing and prior reaction of the gases. A complete reaction provides a greater opportunity for a good quality film. If the gas flow is uncontrolled, the chemical reaction will not be optimal and the result will likely be a film which is not of uniform composition. When the film is not of uniform composition, the proper functioning of the semiconductor is impaired. Thus it is important that an injector design facilitates the desired flow of the gases in a controlled manner.

In a prior art injector, owned by the assignee and described in U.S. Pat. No. 5,136,975, a number of stacked plates each including a number of linear hole arrays is utilized. The plates produce a number of cascaded hole arrays and a chute surrounded by a cooling plate is positioned beneath the last hole array. The chute includes a central passage and ducts are formed between the chute and the cooling plate. Chemical lines deliver gases to a top plate which discretely conveys the gases to the top of individual cascaded hole arrays. The gases are fed through cascaded hole arrays which cause the gas to flow in an increasingly uniform manner. The chute passage receives the gases individually and then conveys the gases to a region above a wafer. In this region, the gases mix, react and then form a film or layer on the wafer.

The cascading action described above provides an uniformly distributed gas flow. However, flow control and simplicity of injector design can be improved.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of this invention to provide an improved apparatus for delivering gaseous chemicals to a surface.

More particularly, it is an object of this invention to provide an improved injector for delivering gaseous chemi-

cals in a controlled manner to a surface for depositing films or layers on the surface by chemical vapor deposition (CVD).

Another object of this invention is to provide a simple injector fabricated from a single block of material, thereby eliminating complicated machined parts requiring precision alignment and positioning.

A further object of this invention is to provide an injector free from internal seals, thereby minimizing maintenance and associated costs.

A further object of this invention is to provide a method for manufacturing the injector of this invention.

A related object of this invention is to provide an injector which improves the uniformity of films deposited on wafers.

These and other objects are achieved by the injector herein disclosed comprising an elongated member with end surfaces and at least one gas delivery surface extending along the length of the member and which includes a number of elongated passages formed therein. Also formed within the member are a number of thin distribution channels which extend between the elongated passages and the gas delivery surface. In another embodiment of the invention a number of metering tubes may be inserted into each elongated passage and are spaced from the walls of said passages and extend between the ends. The metering tubes may contain openings of varying form and dimension which may be directed away from the distribution channels. The metering tubes receive a gaseous chemical which is conveyed along the metering tubes, whereby the gas flows out of the openings, and is conveyed through the corresponding distribution channel and is directed in a substantially controlled manner along the length of the gas delivery surface. In the instance where a number of gases are employed, the distribution channels direct the distribution of such gases to a region where mixing of the gases is desired. In addition the distribution channels prevent chemical fouling of the injector by preventing premature chemical reaction of the gases. The gases are directed to a desired region where they mix, react and form a uniform thin film on the substrate positioned beneath the injector.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the invention become apparent upon reading of the detailed description of the invention provided below and upon reference to the drawings, in which:

FIG. 1 is a side elevated view of an injector in accordance with one embodiment of the present invention.

FIG. 2 is a cross-sectional view taken along the line 2—2 of FIG. 1. of one embodiment of the injector.

FIG. 3 is a cross-sectional view of an injector in accordance with a second embodiment of the invention.

FIG. 4 is a cross-sectional view of an injector in accordance with a third embodiment of the invention.

FIG. 5 is a cross-sectional view of an injector in accordance with a fourth embodiment of this invention.

FIG. 6 is a cross-sectional view of the metering tube of the injector illustrated in FIGS. 4 and 5.

FIG. 7 illustrates a top plan view of one embodiment of an opening pattern in the metering tube of the injector shown in FIGS. 4, 5 and 6.

FIG. 8 is a top plan view of an alternative opening pattern in the metering tube of the injector shown in FIGS. 4, 5 and 6.

FIG. 9 illustrates a top plan view of a slotted opening in the metering tube of the injector shown in FIGS. 4, 5, and 6.

FIG. 10 is a top plan view of another alternative opening pattern in the metering tube of the injector shown in FIGS. 4, 5 and 6.

FIG. 11 is a top plan view of yet another alternative opening pattern in the metering tube of the injector shown in FIG. 4, 5 and 6.

FIG. 12 illustrates an enlarged partial side view of the flange and metering tube attachment to the injector.

DETAILED DESCRIPTION OF THE INVENTION

Turning to the drawings, wherein like components are designated by like reference numerals in the figures, FIGS. 1 and 2 represent one embodiment of the injector of the present invention. The injector 10 comprises a member or block which includes front 11, back 12, top 9, bottom 14 and end 15 surfaces. In this embodiment of the invention, the bottom surface 14 is the gas delivery surface. Positioned beneath injector 10 is a substrate 16.

The injector 10 includes a first elongated passage 17 formed in the injector 10 and extending between the end surfaces 15. One end surface 15 is closed. Chemical delivery line 13 leads to the end of the elongated passage 17. Additionally, formed in the injector 10 is a distribution channel 18 which extends between the elongated passage 17 and the gas delivery surface 14. A view along the length of the injector would show that the distribution channel 18 extends across the substrate 16. In this embodiment a second elongated passage 19 is formed within the injector 10, for circulation of a liquid or gas to control the temperature of the injector 10.

In a CVD process the gas which contains the elements to be deposited are introduced via chemical line 13 and flow along the passage 17 and from this passage 17 to the gas delivery surface 14 along the thin distribution channel 18. The gas flows out of the distribution channel 18 and exits the injector 10 along the length of the gas delivery surface 14, whereby the gas is delivered to a substrate as indicated generally by the arrows in FIG. 2. The gas is distributed by the injector in a substantially controlled linear manner. Although the member 10 has been described as a rectangular block, it can take any shape. The gas delivery surface 14 can be configured to enhance the distribution of the gas.

In many applications a number of gases must be reacted to deposit a proper composition of a film or layer on an substrate. In such instances a plurality of passages is provided, as shown in FIG. 3, a second embodiment of the present invention. Injector 10 contains a plurality of first elongated passages 17, each extending between the end surfaces 15. A chemical delivery line 13 is attached to each passage 17. A plurality of distribution channels 18 are formed in the injector 10 and are spaced apart from one another. Each distribution channel 18 extends between a separate first elongated passage 17 and the gas delivery surface 14. Gases enter the passages 17 and are conveyed through the distribution channels 18 to the gas delivery surface 14, where such gases mix uniformly along the length and provide a film or layer upon the substrate 16. To enhance distribution of the gases, the distribution channels 18 direct the flow of the gases to a desired region adjacent to the substrate 16, as the gases exit along the gas delivery surface 14. Additionally, the distribution channels 18 prevent chemical fouling of the injector 10 by directing the gases away

from the gas delivery surface thereby preventing premature reaction of the chemicals at such surface. Thus, the gases are individually distributed in a substantially linear flow manner to a desired region where the gases have an opportunity to mix, react and deposit a film or layer on substrate 16. Temperature control of the injector 10 may be accomplished by elongated passages 19.

A locator ridge 21, for locating the injector 10 in the CVD chamber, is provided which extends perpendicular from the gas delivery surface 14 and along the length of the surface 14, positioned outside the distribution channels 18. Although the locator ridge 21 has been described as extending from the gas delivery surface 14, it can be placed at other surfaces of the member 10.

In CVD applications it is desirable to maintain controlled flow and concentration of the gas introduced into the process. A metering tube 22 can be provided to maintain controlled flow and concentration. The metering tube 22 can also provide for control of the gas flow profile. In some instances it is desirable to provide a specified gas flow profile to compensate for variables in the CVD reaction area which can cause incomplete reaction of the gases and films which are not uniform in composition. For example, it may be desirable to direct a greater volume of gas to a particular area of the substrate 16. The third embodiment of the present invention illustrated in FIG. 4 provides a metering tube 22 containing an opening 23, inserted into the first elongated passage 17. The metering tube 22 is spaced from the walls of the passage 17, and extends between the end surfaces 15. A distribution channel 18 is formed within injector 10, and extends between the elongated passage 17 and the gas delivery surface 14. In one variation of this embodiment, the metering tube 22 includes openings 23, as depicted in FIG. 4. In another variation of this embodiment, the metering tube 22 is made from a porous material and openings are not included in the metering tube 22.

The metering tube 22 receives a gas from chemical line 13 and distributes the gas along the elongated passage 17, where the gas then flows through the distribution channel 18 to the gas delivery surface 14 and out to the substrate 16.

FIG. 5 illustrates a forth embodiment of the present invention. A plurality of first elongated passages 17 are formed within injector 10, each extending between the end surfaces 15. A plurality of distribution channels 18 are formed in the injector 10 and the distribution channels 18 are spaced apart from one another. Each distribution channel 18 extends between a separate first elongated passage 17 and the gas delivery surface 14. At least one metering tube 22 containing an opening 23, is inserted into at least one of the first elongated passages 17. The metering tube 22 is spaced from the walls of the passage 17, and extends between the end surfaces 15. In a variation of this embodiment, a separate metering tube 22 may be inserted into each of the plurality of first elongated passages 17 provided. A chemical delivery line 13 is attached to each metering tube 22.

Referring again to FIG. 5, a locator ridge 21, for locating the injector 10 in the CVD chamber, is provided which extends perpendicular from the gas delivery surface 14 and along the length of the gas delivery surface 14, positioned outside the distribution channels 18. Temperature control may be accomplished by second elongated passages 19. Locator ridge 21 provides the mechanism for locating the injector 10 within the CVD chamber.

Thus, in the fourth embodiment, chemical delivery lines 13 are attached to corresponding metering tubes 21, or to a combination of metering tubes 21 and first elongated pas-

sages 17, and convey gaseous chemicals thereto. The gases pass through the metering tubes 22 and into the surrounding first elongated passages 17, and are conveyed through the corresponding distribution channels 18 to the gas delivery surface 14 along the length of the surface. The distribution channels 18 enhance distribution of the gases by individually directing the flow of the gases to a desired region adjacent to the substrate 16. The metering tubes 21 may be used to adjust the flow profile of one particular gas, or a number of gases to deliver gases of varying concentration at desired regions adjacent to the substrate, thereby controlling the chemical reaction rate occurring within the CVD chamber. By controlling the chemical reaction rate a more uniform film can be deposited on the substrate 16.

In order to adjust the gas flow pattern, many variations may be made in the metering tubes 22. Where a metering tube comprises openings 23, such openings may be directed away from the distribution channel 18. Alternatively, the openings 23 may be directed toward the distribution channel 18. In the preferred embodiment, the openings are opposite the distribution channel. The various configurations of metering tubes 22 are more fully appreciated with reference to FIGS. 6 through 10.

FIG. 6 depicts a cross-sectional view of metering tube 22 including an opening 23. Gas is conveyed through the metering tube and is outputted through opening 23. The configuration of opening 23 controls the gas outlet flow profile.

FIGS. 7 through 10 show the various opening configurations contemplated by the invention to provide adjustment to a desired gas flow pattern. Referring to FIG. 7, the openings 23 comprise a plurality of in-line holes 24 extending along the length of the metering tube 22. In this embodiment, the holes 24 are of equal diameter and equal spacing along the tube 22.

An alternative opening pattern is shown in FIG. 8, where the openings 23 comprise a plurality of in-line slots 25 extending along the length of the metering tube 22. The slots are of equal dimension and spacing along the tube 22.

A further alternative opening pattern is depicted in FIG. 9, where a continuous slot 26 extends along the length of the metering tube 22.

A still further alternative opening configuration is illustrated in FIG. 10. The openings 27 comprise a plurality of openings which vary in dimension, or spacing or a combination of both, along the length of the metering tube 22. The openings may be holes or slots. In one, the openings begin at a small dimension at each end of the metering tube 12, and gradually increase in dimension toward the center of the metering tube 22. The gas volume flow rate will be greater from the larger openings and thus the gas outlet flow pattern can be controlled.

A yet further alternative opening configuration is shown in FIG. 11. The openings 28 comprise a plurality of openings which are the same dimension and pitch along the length of the metering tube 22. Near the center of the metering tube 22, additional openings 29 are provided, such that the volume flow rate will be greater from the center of the metering tube 22.

Finally, the attachment mechanism between the metering tube 22 and the chemical delivery lines 13 is more fully appreciated by reference to FIG. 12 which shows an enlarged partial side view of an attachment mechanism and metering tube of the injector. A metering tube 22 is inserted into a first elongated passage 17 and extends between the end surfaces 15. A flange 30 is attached to the chemical

delivery line 13 and the flange is then attached to the end 15 of the injector 10. A seal 31 is provided therebetween. The metering tube 22 is attached to the flange and provides for an airtight seal.

Many variations of chemicals are used in CVD processes. The invention provides for various chemical delivery lines. In one embodiment the chemical delivery lines 13 may convey a combination of tetrachlorosilane (TEOS) and nitrogen in one line, nitrogen in a second line and ozone mixed with oxygen in a third line to form a layer of silicon dioxide.

As the foregoing illustrates, there are many variations possible for practicing the invention. The preferred embodiment comprises five first elongated passages, with five metering tubes inserted therein. The dimensions may vary, however in this preferred embodiment each passage is approximately $\frac{3}{4}$ inches in diameter, and the outer diameter of each metering tube is approximately $\frac{1}{4}$ inch diameter. The metering tube contains fifty equally spaced holes of equal dimension along the length of the metering tube.

Various manufacturing techniques known in the art can be used to form the distribution channels 18. In the preferred embodiment the distribution channels are formed by a wire electrode discharge machine (EDM).

A particular advantage made apparent by the above description, is the simplicity of design of the injector. The invention eliminates the need for seals within the injector body. The present invention eliminates the requirement for welding and bolting of various internal body components. The present invention eliminates the requirement for precision alignment and positioning of internal body components necessary for proper gas flow in many injectors. The elimination of such components should minimize maintenance requirements, thereby reducing costly down time. In particular, the injector of the present invention will not have to be disassembled and rebuilt to replace failed internal seals. In addition, gaseous chemical leakage should be reduced.

Another improvement of the present invention is apparent by referring to the metering tubes. The metering tubes are replaceable, thus one can vary the configuration of gas flow desired by simply detaching one metering tube and inserting another metering tube of differing aperture placement or diameter. No disassembly of the injector body is required. Further, modeling or experimentation allow customized metering tubes to be manufactured for particular applications or machines.

The simplicity of the design favors formation of precise components and thus, greater control of gas distribution.

Thus, the foregoing demonstrates an improved injector for delivering gaseous chemicals to a surface which fully satisfies the aims, advantages and objects set forth above.

While the invention has been described in connection with specific embodiments, it is evident that many variations, substitutions, alternatives and modifications will be apparent to those skilled in the art in light of the foregoing description. Accordingly, this description is intended to encompass all such variations, substitutions, alternatives and modifications as fall within the spirit of the appended claims.

What is claimed:

1. An injector for providing uniform gas distribution to a substrate, comprising:

a single elongated member having end surfaces and one planar elongated external gas delivery surface extending along the length of the member directly facing and parallel to the substrate;

at least a first elongated cylindrical passage formed in said elongated member and extending between the end surfaces serving to receive a gas;

a thin, elongated distribution slot of substantially constant width formed in said single elongated member and extending directly between said first elongated cylindrical passage and said gas delivery surface for carrying gas directly and uniformly from said elongated passage for distribution uniformly in a continuous, unobstructed manner along the elongated external gas delivery surface.

2. The apparatus of claim 1, further comprising at least one second elongated passage formed in said elongated member and extending between the ends serving to receive a medium for temperature control of the injector.

3. The apparatus of claim 1 wherein the thin distribution channel is formed by EDM machining.

4. An injector for providing gas distribution to a substrate, comprising:

- a single elongated member having end surfaces and at least one planar elongated external gas delivery surface extending along the length of the member directly facing and parallel to the substrate;
- a plurality of first elongated cylindrical passages formed in said elongated member and extending directly between the end surfaces, each serving to receive a gas;
- a plurality of thin, spaced, elongated distribution slots each of substantially constant width formed in said single elongated member, one of said plurality of slots extending directly between each of said first elongated cylindrical passages and the gas delivery surface for carrying the gases directly and uniformly from the respective passage to the gas delivery surface for uniform distribution in a continuous, unobstructed manner along the substrate placed adjacent said delivery surface.

5. The apparatus of claim 4, further comprising at least one ridge extending from the gas delivery surface positioned outside of said distribution slots and extending along the length of said surface for positioning the injector.

6. The apparatus of claim 4, further comprising at least one second elongated passage formed in said elongated member and extending between the ends serving to receive a medium for temperature control of the injector.

7. The apparatus of claim 4 wherein the plurality of thin distribution channels are formed by EDM machining.

8. An injector for providing uniform gas distribution to a substrate comprising:

- a single elongated member having end surfaces and at least one planar external gas delivery surface extending along the length of the member directly facing and parallel to the substrate;

at least a first elongated cylindrical passage formed in said elongated member and extending between the end surfaces;

at least a first thin, uniform elongated distribution slot of substantially constant width formed in said elongated member and extending directly between said first elongated cylindrical passage and said gas delivery surface for carrying gas directly and uniformly from said elongated passage for distribution uniformly in a continuous, unobstructed manner along the gas delivery surface; and

- a metering tube inserted into said first elongated cylindrical passage and spaced from the walls of said first

elongated passage and extending between the ends, serving to receive a gas and distribute the gas along the elongated passage where it flows through the distribution slot to the substrate.

9. The apparatus of claim 8, further comprising at least one second elongated passage formed in said elongated member and extending between the ends serving to receive a medium for temperature control of the injector.

10. The apparatus of claim 8 wherein the metering tube comprises a porous material.

11. The apparatus of claim 8 wherein the metering tube comprises a slot extending along the length of said metering tube.

12. The apparatus of claim 11 wherein said slot is directed away from the distribution channel.

13. The apparatus of claim 8 wherein the metering tube comprises a plurality of openings along the length of said metering tube, said openings being directed away from the distribution slot.

14. The apparatus of claim 13 wherein said plurality of openings vary in dimension along the length of said metering tube.

15. The apparatus of claim 13 wherein said plurality of openings vary in spacing along the length of said metering tube.

16. The apparatus of claim 8 wherein the thin distribution channel is formed by EDM machining.

17. An injector for providing uniform gas distribution to a substrate, comprising:

- a single elongated member having end surfaces and one planar elongated external gas delivery surface extending along the length of the member directly facing and parallel to the substrate;

- a plurality of elongated cylindrical passages formed in said elongated member and extending between the end surfaces;

- a plurality of thin, spaced, elongated distribution slots each of substantially constant width, one for each of said elongated passages, formed in said elongated member and extending directly between each of said elongated cylindrical passages and the gas delivery surface, said distribution slots spaced from one another, for carrying the gases from said elongated cylindrical passages to said gas delivery surface for uniform distribution in a continuous, unobstructed manner along the length of the substrate; and

- a plurality of metering tubes, one for each of said elongated cylindrical passages, one inserted into each of said elongated cylindrical passages and spaced from the walls of each of said first elongated cylindrical passages and extending between the ends serving to receive a gas and distribute the gas along the associated elongated passage where it flows uniformly through the distribution slot to the substrate.

18. The apparatus of claim 17, further comprising at least one ridge extending from the gas delivery surface positioned outside said distribution slots and extending along the length of said surface for positioning the injector.

19. The apparatus of claim 17, further comprising at least one second elongated passage formed in said elongated member and extending between the ends serving to receive a medium for temperature control of the injector.

20. The apparatus of claim 17 wherein at least one of said plurality of metering tubes comprises a porous material.

21. The apparatus of claim 17 wherein at least one of said plurality of metering tubes comprises a slot extending along the length of said metering tube, said slot being directed away from the distribution slot.

22. The apparatus of claim 17 wherein at least one of said plurality of metering tubes comprises a plurality of openings along the length of said metering tube, and said openings being directed away from the distribution slot.

23. The apparatus of claim 22 wherein said plurality of openings vary in dimension along the length of said metering tube.

24. The apparatus of claim 22 wherein said plurality of openings vary in spacing along the length of said metering tube.

25. The apparatus of claim 17 further comprising a flange attached to said metering tube, and said flange is attached to one of said end surfaces of the elongated member.

26. The apparatus of claim 17 wherein the plurality of thin distribution channels are formed by EDM machining.

* * * * *



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Ishii

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[45] Date of Patent: Nov. 11, 1997

[54] PLASMA PROCESSING APPARATUS AND METHOD

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[21] Appl. No.: 566,154

[22] Filed: Dec. 1, 1995

[30] Foreign Application Priority Data

Dec. 5, 1994 [JP] Japan 6-330245

[51] Int. Cl.⁶ H01L 21/00

[52] U.S. Cl. 156/345; 216/67

[58] Field of Search 216/67, 68, 69;
156/643.1, 345; 204/298.34

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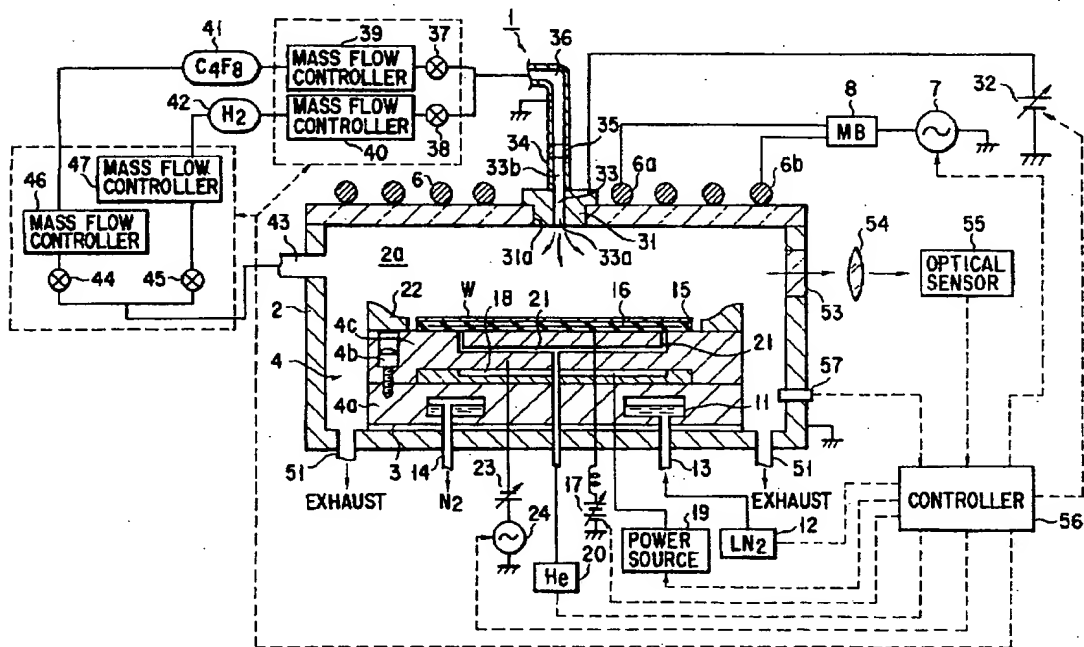
Primary Examiner—William Powell

Attorney, Agent, or Firm—Oblon, Spivak, McClelland, Maier & Neustadt, P.C.

[57] ABSTRACT

A plasma processing apparatus comprises a chamber for storing an object, a gas supply unit for supplying processing gas into the chamber, and high-frequency antenna, provided at least either the inside or outside of the chamber to oppose the object, for generating processing gas supplied into the chamber for processing the object, a high-frequency power source for supplying high-frequency power to the high-frequency antenna, and an electrode, provided to oppose the object and to be insulated from the high-frequency antenna and set at a reference potential, for providing a uniform electric field above the object.

11 Claims, 5 Drawing Sheets



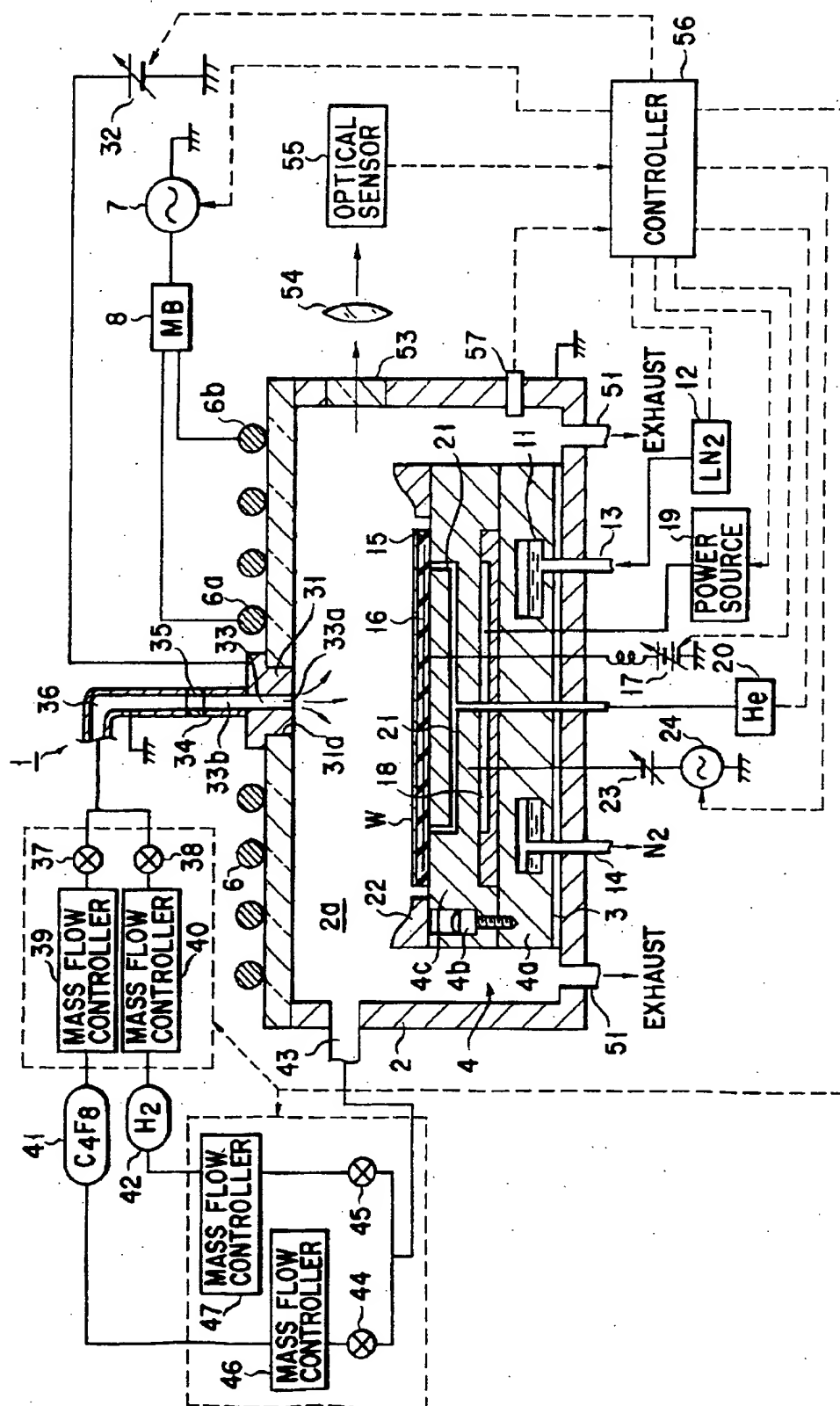


FIG. 1

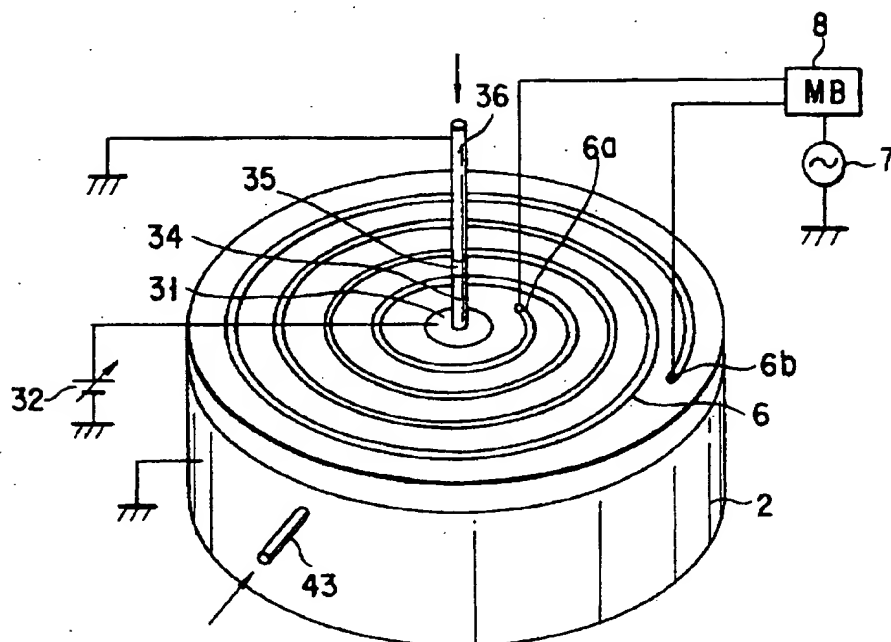


FIG. 2

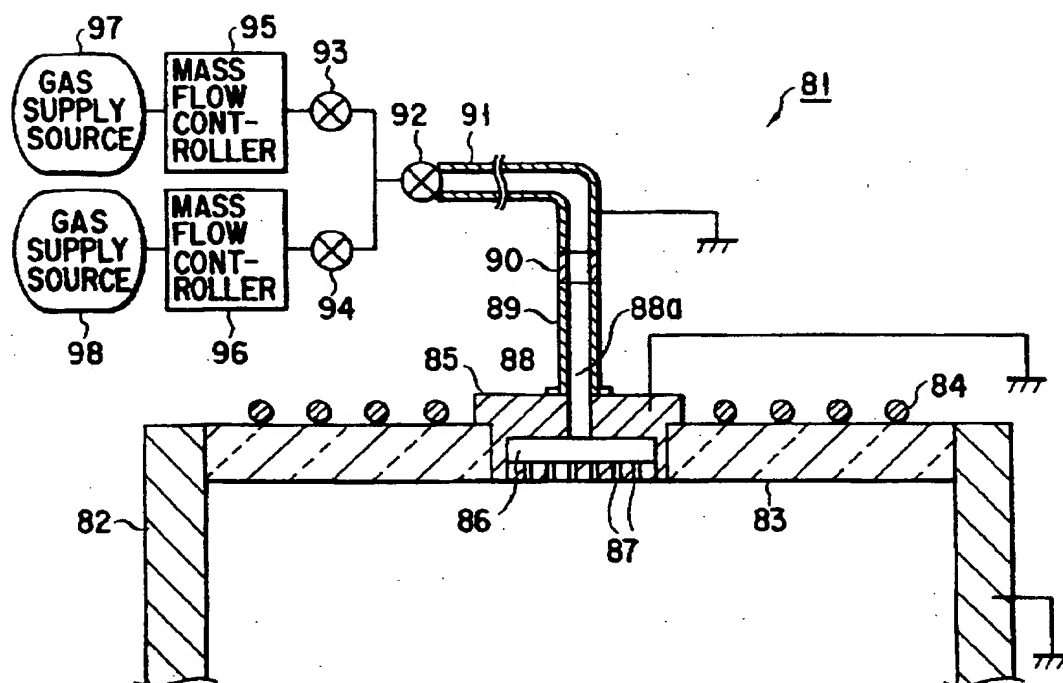


FIG. 4

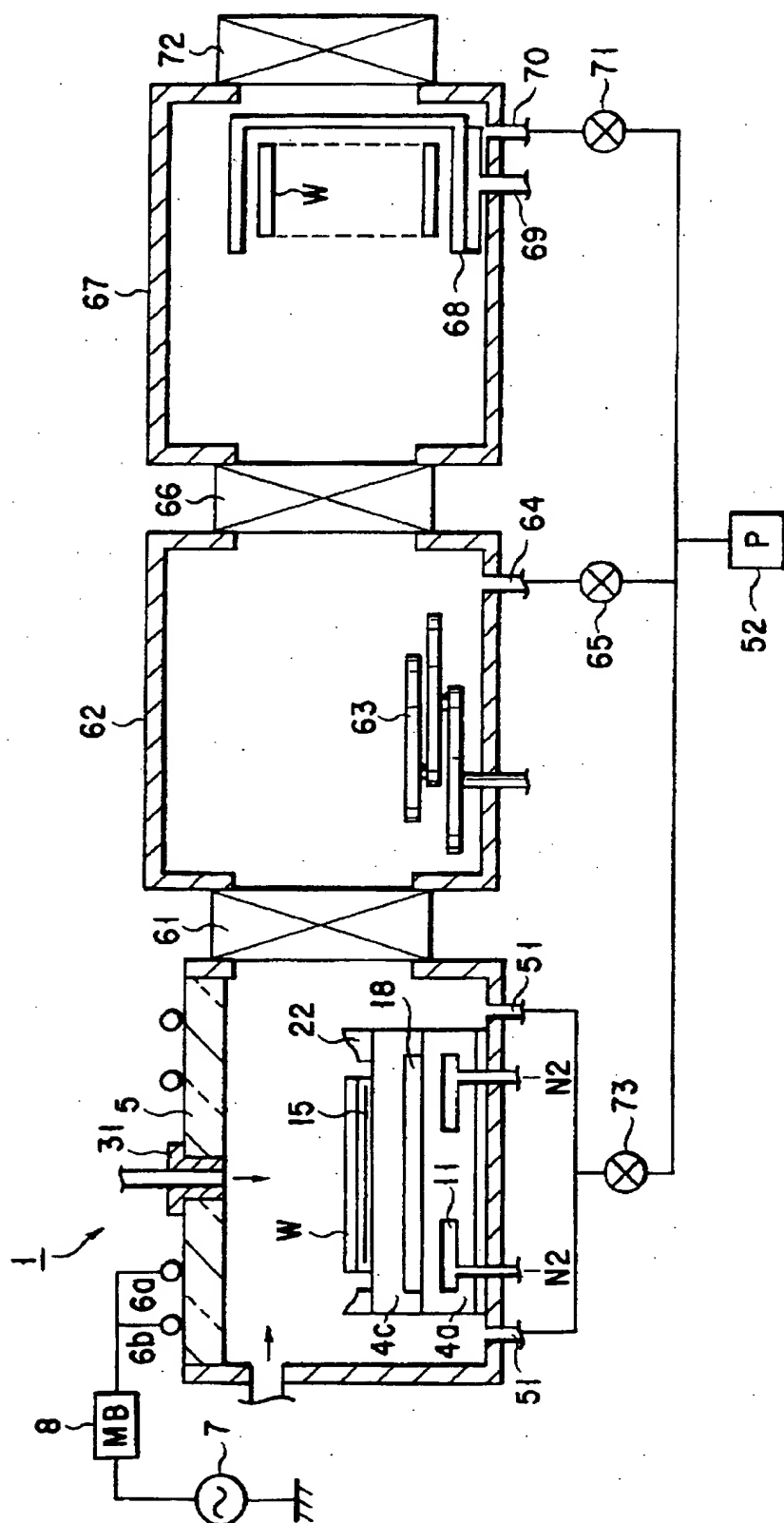


FIG. 3

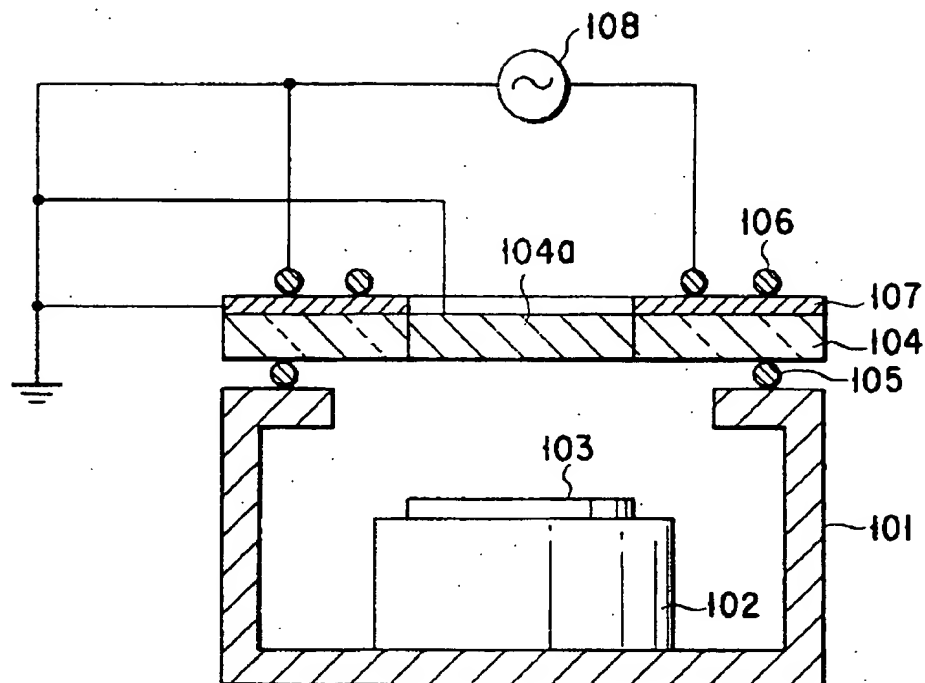


FIG. 5

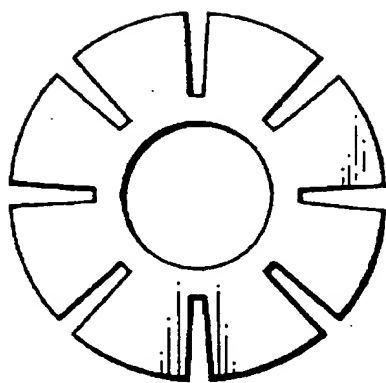


FIG. 6A

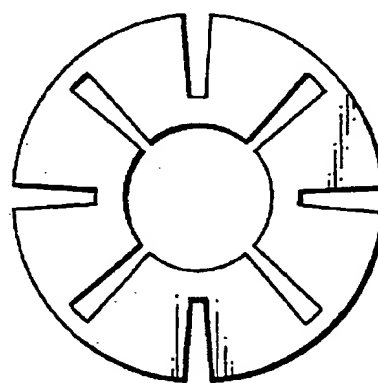


FIG. 6B

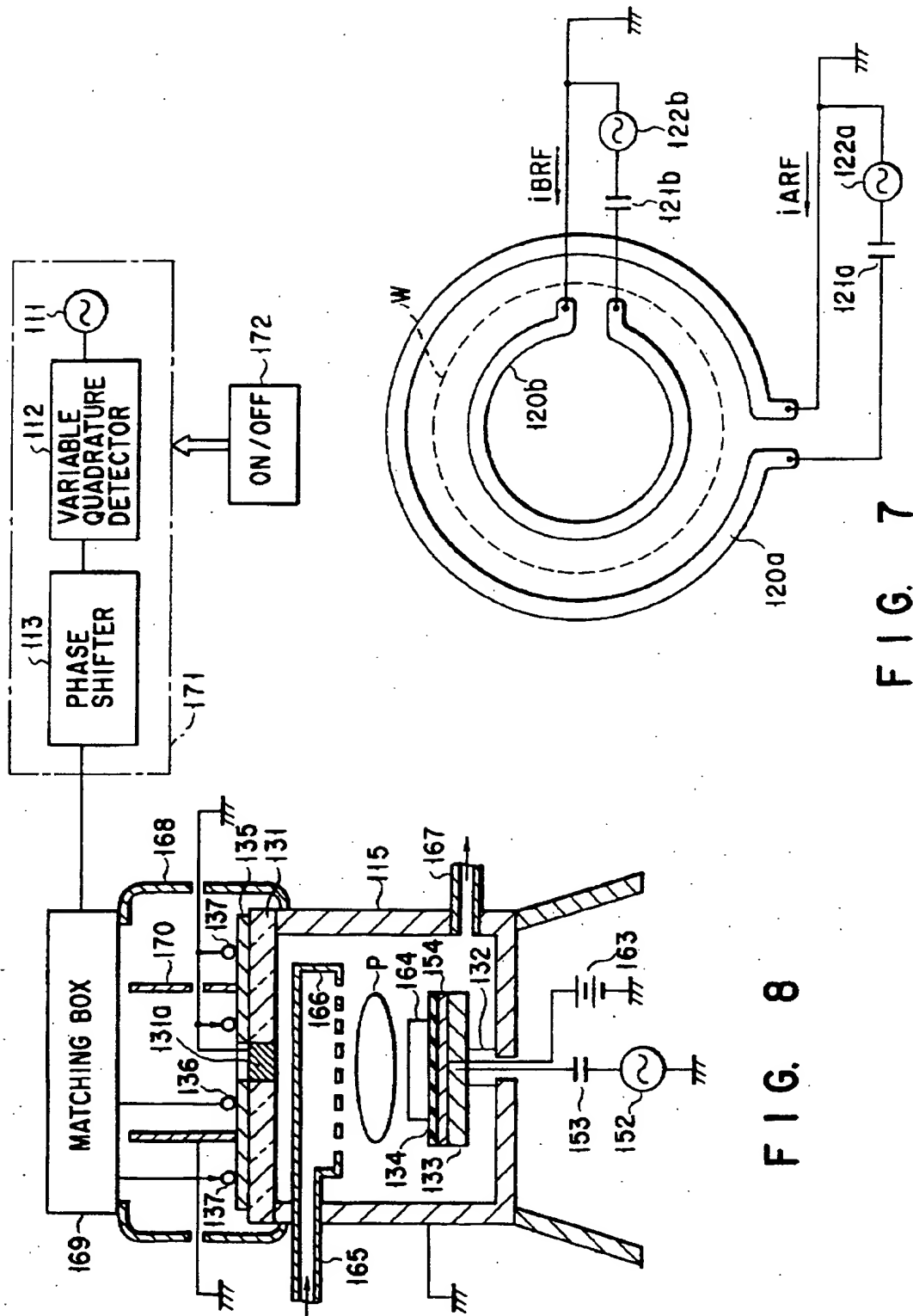


FIG. 7

FIG. 8

PLASMA PROCESSING APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a plasma processing apparatus and a plasma processing method.

2. Description of the Related Art

A parallel plate type plasma processing apparatus using high frequency (RF) waves has been widely utilized for plasma-processing, e.g., a semiconductor wafer (which will be referred to as "wafer" hereinafter) in a processing chamber. It has a structure in which plasma is generated between the parallel plate electrodes by applying high frequency to one of or both of the electrodes, and a plasma flow is made incident on the processed surface of the object by the self bias potential difference between the plasma and the object to thereby carry out, for example, etching processing to the object.

Ultra fine processing, using the conventional plasma processing apparatus such as a parallel plate type plasma processing apparatus, in units of sub-micron or even sub-half micron has been increasingly in demand as ultra-high integrated semiconductor devices are produced. It is, however, difficult to execute it. To do so using the plasma processing apparatus, it is essential to control high-density plasma with high precision in a low-temperature atmosphere. Also, it is necessary for the plasma to have an expansive area as well as high uniformity so as to deal with a wafer having a large diameter. Furthermore, if electrodes are used in the plasma processing apparatus, they cause heavy metal contamination per se at the time when plasma occurs. Ultra fine processing has been, in particular, confronted by the heavy metal contamination problem.

Although magnetron plasma etching or growing means have been proposed to meet these technical requirements, they are not enough to avoid damage to the wafer W. A variety of approaches have been made so far to establish a new plasma source causing no damage to the wafer W. For instance, the European Patent Publication No. 379828 discloses a high-frequency induction plasma generation apparatus using a high-frequency antenna.

This high-frequency induction plasma generation apparatus has a structure in which the surface of a processing chamber, which opposes a wafer holding base, is made of insulating material such as quartz glass and an outer wall surface thereof is equipped with a high-frequency antenna constructed by, e.g. a spiral coil. High-frequency power is applied to the high-frequency antenna to thereby form a high frequency electromagnetic field in the processing chamber, to ionize gas by colliding electrons flowing in the electromagnetic field space with neutral particles of the processing gas, and to thereby generate plasma.

Meanwhile, if plasma processing is carried out using the above-mentioned high-frequency induction type plasma processing apparatus, the density of plasma induced in the processing housing tends to become irregular, particularly, in the radial direction. In the case of carrying out plasma processing with ultra-high precision as high as a sub-half micron, it is necessary to generate plasma with high density, uniformity and reproducibility in the processing housing. Therefore, the technique of providing uniform plasma density with high precision by the use of the high-frequency induction type plasma processing apparatus has to be urgently established.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an improved plasma processing apparatus and method which can control, with strong precision, plasma having high density, high uniformity and high reproducibility.

Another object of the present invention is to provide an improved plasma processing apparatus and method which can provide a uniform reaction speed if used in etching processing and which can carry out plasma processing with the same reaction speed between the center and periphery of the object.

According to the present invention, there is provided a plasma processing apparatus, comprising: a chamber storing an object; gas supply means for supplying processing gas into the chamber; a high-frequency antenna, provided at least one of the inside and outside of the chamber to oppose the object, for generating processing gas supplied into the chamber for processing the object; a high-frequency power source for supplying high-frequency power to the high-frequency antenna; and an electrode provided to oppose the object and to be insulated from the high-frequency antenna and set at a reference potential, for providing a uniform electric field above the object.

According to the present invention, there is provided a plasma processing apparatus comprising: a chamber for storing the object; gas supply means for supplying processing gas to a central portion of the object to provide a uniform gas flow above the object within the chamber; a high-frequency antenna, provided at least either the inside or outside of the chamber to oppose the object, for generating processing gas supplied into the chamber for processing the object; and a high-frequency power source for supplying high-frequency power to the high-frequency antenna.

According to the present invention, there is provided a plasma processing method comprising the steps of: supplying processing gas into a chamber in which an object is stored; supplying high-frequency power to a high-frequency antenna, provided at least one of the inside and outside of the chamber to oppose the object, for generating processing gas supplied into the chamber for processing the object; and applying a ground potential to an electrode, provided on a central portion of the object, for providing a uniform electric field above the object.

According to the present invention, there is provided a plasma processing method comprising the steps of: supplying processing gas to a central portion of an object, which is stored in a chamber, to provide a uniform processing gas flow above the object; and supplying high-frequency power to a high-frequency antenna, provided at least one of the inside and outside of the chamber to oppose the object, for generating processing gas supplied into the chamber for processing the object.

Additional objects and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and obtained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate presently preferred embodiments of the invention and, together with the general description given above and the detailed descrip-

tion of the preferred embodiments given below, serve to explain the principles of the invention.

FIG. 1 is a schematically sectional view showing plasma etching equipment according to the first embodiment of the present invention;

FIG. 2 is a perspective view of the plasma etching equipment of FIG. 1;

FIG. 3 is a schematically sectional view showing the plasma etching equipment and peripheral apparatuses thereof;

FIG. 4 is a partially sectional view showing plasma etching equipment according to the second embodiment of the present invention;

FIG. 5 is a schematically sectional view of the plasma etching equipment according to the third embodiment of the present invention;

FIGS. 6A and 6B are plan views showing an electrostatic shield plate used in the plasma equipment shown in FIG. 5;

FIG. 7 is a view showing a double ring antenna applicable to the plasma equipment of FIGS. 1, 4 and 5; and

FIG. 8 is a schematically sectional view of the plasma equipment provided with a double ring antenna according to the fourth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of a plasma processing apparatus according to the present invention will now be described with reference to appended drawings. A plasma etching equipment 1 shown in FIG. 1 includes a processing housing 2 molded into a circular cylinder or a rectangular cylinder out of conducting material such as aluminum. Predetermined etching process is carried out in a processing chamber 2a formed in the processing housing 2.

The processing housing 2 is grounded and provided with a substantially cylindrical holding base 4 for holding an object, e.g. a semiconductor wafer W at its base via an insulating plate made of, e.g. ceramics. An insulating material 5 made of, e.g. quartz glass or ceramics is provided airtightly on the upper plate of the processing housing 2 which almost opposes the holding surface of the wafer W held on the holding base 4. A high frequency antenna 6 is formed into spiral, coil or loop shape out of a conductor, e.g. a copper plate, aluminum or stainless steel, is arranged on the outer wall of the insulating material 5. The antenna 6 can do with only having a function to generate plasma, and if frequency is high, it might be enough for the antenna to be coiled only once.

As shown in FIG. 2, terminals 6a and 6b of the high frequency antenna 6 are connected to a high frequency power source 7 for generating plasma through a matching circuit 8. Since the matching circuit 8 adjusts current values, the alternating electric field, that is, plasma density can be controlled depending on the amount of current flowing through the antenna 6.

The holding base 4 mainly consists of a susceptor holding base 4a, which is molded into a cylindrical shape out of aluminum, and a susceptor 4c which is detachably provided on the susceptor holding base 4a by a bolt 4b. The detachably provided susceptor 4a helps easy maintenance.

A temperature adjuster, such as a cooling jacket 11, is provided on the susceptor holding base 4a. Refrigerant such as liquid nitrogen is introduced from a refrigerant source 12 into the jacket 11 by way of a refrigerant intake pipe 13. Nitrogen gas resulting from liquid nitrogen which has been

vaporized by means of heat exchange when circulating through the cooling jacket 11 is discharged from the refrigerant exhaust pipe 14 outside of the processing housing 2. With this structure, cold of liquid nitrogen with a temperature of, e.g. -196°C . is transferred from the cooling jacket 11 to the semiconductor wafer W through the susceptor 4c, making it possible to cool the processed surface of the wafer W down to a desired temperature.

An electrostatic chuck 15, which has almost the same area as that of the wafer, is formed on the wafer holding portion on the upper surface of the susceptor 4c molded substantially into a cylindrical shape. The electrostatic chuck 15 is formed, for instance, by sandwiching a conducting film 16, e.g. a copper foil, between two polymeric polyimide films in an insulating manner. The conducting film 16 is connected to a variable DC voltage source 17 by a lead line. The semiconductor wafer W is adhered to and held on the upper surface of the electrostatic chuck 15 by coulomb force.

A moisture adjusting heater 18 is provided at the bottom of the susceptor 4C between the electrostatic chuck 15 and the cooling jacket 12. The transfer of cold from the cooling jacket is controlled by adjusting power supplied from a power source 19 to the moisture adjusting heater 18, thereby making temperature control of the processed surface of the semiconductor wafer W possible.

A gas flow path 21 is formed through the susceptor holding base 4a and the susceptor 4c to supply heat-transfer gas (or back cooling gas), e.g. He, from a gas source 20 to the reverse face of the semiconductor wafer W or to coupling portions of elements of the susceptor 4c. A focusing ring 22 is arranged on the upper edge portion of the susceptor 4c in such a manner as to surround the semiconductor wafer W. The focusing ring 22 is made of a high-resistant element which does not attract reaction gas, such as ceramics or quartz glass. The ring 22 serves to make the reaction gas effectively incident on the semiconductor wafer W only.

The susceptor 4c is connected to a high-frequency power source 24 through a matching capacitor 23. While processing is going on, a bias potential occurs between the susceptor 4c and plasma if applying high-frequency power of, e.g. 2 MHz to the susceptor 4c, so that a plasma stream is attracted effectively to the processed surface of the object.

A ground electrode 31 made of a conductor or a semiconductor is provided at the center of the high-frequency antenna 6 through the insulating material 5 of the processing housing 2 airtightly. The same material as that of the processing housing 2, i.e., aluminum can be used for the ground electrode 31. Si single crystal, SiC or C, which are the same material as that of the semiconductor wafer, can be also used as a material to prevent heavy metal contamination.

The ground electrode 31 is connected in series to a variable load circuit device 32. The variable load circuit device 32 can control the potential of the ground electrode 31 by adjusting the load. This makes it possible to control the intensity of the bias field occurring at the center of the semiconductor wafer W to be the same as the field intensity of the peripheral portion, thereby controlling the bias field of the plasma occurring in the processing housing 2 to be uniform.

If the object, that is, semiconductor wafer W is 8 inches in size, the diameter of the ground electrode 31 is set at around 80 mm. Since the size of the ground electrode 31 is determined depending on the processing types or the like, it may be larger than the object. The bottom surface 31a of the ground electrode 31 is molded to be flush with the surface of the insulating material 5.

A processing gas supply path 33 is formed perpendicularly within the ground electrode. The outlet of the supply path 33, that is, the opening portion on the side of the processing chamber 2a serves as a supply port 33a, the inlet thereof, that is, the opening portion on the side of the outside of the processing housing 2 as a gas inlet 33b. A first conductive supply pipe 34 is connected to the first supply pipe 34. A second supply pipe 36 is connected to the gas inlet 33b through an insulating material 35, and is grounded. Thus, high frequency to be applied to the first supply pipe 34 is interrupted by the insulating material 35, thereby stabilizing the operation of the ground electrode.

The second supply pipe 36 is connected, through valves 37 and 38 and mass flow controllers 39 and 40, to processing gas supply sources 41, 42. In this embodiment, C_4F_8 gas is supplied from the processing gas supply source 41 and H_2 gas from the processing gas supply source 42.

A gas supply pipe 43 made of quartz glass or ceramics is provided on the side surface of the processing housing 2 above the susceptor 4c. The pipe 43 is connected, via the valves 44, 45 and mass flow controllers 46 and 47, to the processing gas supply sources 41 and 42, as well.

An exhaust pipe 51 is connected to the bottom of the processing housing 2. As shown in FIG. 3, since the atmosphere within the processing housing 2 can be exhausted by a vacuum pump 52 through a vacuum exhaust valve 73, the atmosphere of the processing chamber 2a can be reduced to an arbitrary pressure.

Next, the structure of the control system of the plasma etching equipment 1 having the above-mentioned structure will be described.

A transparent window 53 made of transparent material such as quartz glass is provided on one of the side walls of the processing housing 2. Light within the processing chamber 2a is transmitted to an optical sensor 55 through an optical system 54. From the optical sensor, a signal relating to an emission spectrum generated from the processing chamber 2a is sent to a controller 56. The processing housing 2 is also provided with a sensor 57, a signal relating to pressure in the processing chamber 2a is sent to the controller 56.

The controller 6 sends control signals to the high frequency power source 7 for generating plasma, the variable load circuit equipment 32, a high frequency power source 24 for generating bias voltage, the refrigerant source 12, the power source 19 for adjusting temperature and the back cooling gas source 20, based on a feedback signal from the optical sensor 55 and the sensor 57 and on a present value. The present invention has control in such a way that the potential of the ground electrode 31 and a reaction speed are variable, enabling the optimum adjustment of the operational environment of the apparatus. Further, since the controller 56 controls the processing gas mass flow controllers 39, 40, 47 and 46, the flow rate of the processing gas from the supply port 33a of the ground electrode 31 and from the gas supply pipe 43 can be freely adjusted.

Peripheral machines and apparatuses of the plasma etching equipment 1 will be described with reference to FIG. 3. As shown therein, a load lock chamber 62 is adjacent to and connected via a gate valve 61 which opens and closes freely, to one of the side walls of the processing housing 2 of the plasma etching equipment 1. A transfer machine 63 having a transfer arm which is made of, for example, aluminum and is coated with conductive Teflon to be resistant to electrostatic, is provided in the load lock chamber 62. An exhaust pipe 64 is connected to the load lock chamber 62

from the exhaust port provided on the bottom surface thereof, and the atmosphere of the chamber 62 can be reduced to a vacuum by a vacuum pump 5 by way of a vacuum exhaust valve 65.

A cassette chamber 67 is adjacent and connected to the side wall of the load lock chamber 62 through a gate valve 62 which opens and closes freely. In the cassette chamber 67, a holding base 69 is provided for holding a cassette 68. The cassette 68 can store 25 semiconductor wafers W as one lot. An exhaust pipe 70 is connected to the exhaust port provided on the bottom surface of the cassette chamber 67, whose atmosphere can be reduced to a vacuum by the vacuum pump 52 by way of a vacuum exhaust valve 71. The other side wall of the cassette chamber 67 is brought into contact with the air through the gate valve 72 which freely opens and closes.

The operation of the plasma etching equipment 1 having the above-mentioned structure will be described.

The gate valve 72, which contacts the air, is opened. The cassette 68 which stores the object, i.e. semiconductor wafers W is held on the holding base 69 by a transfer robot (not shown). Then, the vacuum exhaust valve 71 connected to the cassette chamber 67 is opened, and the atmosphere of the chamber 67 is reduced to a predetermined vacuum atmosphere, e.g. 1×10^{-1} Torr.

Furthermore, the gate valve 66 provided between the load lock chamber 62 and the cassette chamber 67 is opened. A semiconductor wafer W is taken out from the cassette 68 mounted in the cassette chamber 67, and is transferred to the load lock chamber 62 by the transfer machine 63. The gate valve 66 is closed. The vacuum exhaust valve 65 connected to the load lock chamber 62 is opened, and the atmosphere of the load lock chamber 62 is reduced to a predetermined vacuum atmosphere, e.g. 1×10^{-3} Torr by the vacuum pump 52.

Next, the gate valve 66 provided between the load lock chamber 62 and the processing housing 2 is opened. The semiconductor wafer W is transferred into the processing chamber 2a of the processing housing by the transfer machine 63, and is passed on to a pusher pin (not shown) on the susceptor 4c. After the transfer machine 63 returns into the load lock chamber 62, the gate valve 66 is closed. Later, a high DC voltage applied to the electrostatic chuck 15, and the semiconductor wafer W is held on the electrostatic chuck 1 by descending the pusher pin, thereby fixedly holding the semiconductor wafer W on the susceptor 4c. During that period, the vacuum valve 73 is opened and the atmosphere of the processing housing 2 is reduced to a predetermined vacuum atmosphere, e.g. 1×10^{-5} Torr using the vacuum pump 44.

Moreover, while heat-transfer (back cooling) gas is being supplied to the reverse surface of the semiconductor W and to the coupling portion of the holding base 4, cold is supplied from the cooling jacket 11 to cool the processed surface of the semiconductor wafer W to a desired temperature. After that predetermined amounts of C_4F_8 and H_2 gas are introduced into the processing chamber 2a through the supply port 33a of the ground electrode 31 provided above the processing chamber 2a and the gas supply pipe 43 provided on the upper side of the processing chamber 2a, respectively.

After the sensor 57 senses that the processing chamber 2a comes to an optimum pressure atmosphere for providing an optimum etching speed which has been calculated using a dummy wafer in advance, a high-frequency power of, e.g. 13.56 MHz is applied to the high-frequency antenna 6 through the matching circuit 8, resulting in the excitation of

plasma in the processing chamber 2a. Then, the bias potential is applied to the holding base 4 by the high-frequency power source 24, whereby the semiconductor wafer W is etched. At that time, if the inner wall of the processing chamber 2a is heated to temperatures of 50° C. to 100° C., or preferably to 60° C. to 80° C., reaction products can be prevented from being adhered to the inner wall of the processing housing 2.

While etching processing is carried out, control signals are sent from the controller 56 to the high-frequency power source 7, the matching circuit 8, variable load circuit device 10 and the high-frequency power source 24 for bias potential, based on the feedback signal from the optical sensor 55 and sensor 57 which observe the environment within the processing housing 2 or on a preset value, thereby controlling the potential of the high-frequency antenna 6 or the potential of the ground electrode 31. In this way, as plasma in the processing housing 2 maintains high density and uniformity, processing conditions are kept at an optimum. If the controller 56 judges that the predetermined etching process is completed, then the application of the high-frequency energy and the supply of the processing gas are stopped and the plasma processing operation is completed.

Since the ground electrode 31 is provided at the center of the high-frequency antenna 6, or, at the portion which opposes the central portion of the semiconductor wafer W, the central portion has an intensified bias field to be equal to that of the peripheral portion. In this respect, therefore, the etching processing is uniformly performed.

Besides, from the processing gas supply path 33, which is formed in the ground electrode 31, the processing gas is introduced into the processing chamber 2a via the supply port 33a and is blown on the semiconductor wafer W. The processing gas is orientated from the center to the periphery of the semiconductor wafer W, with the result that the gas flows uniformly on the semiconductor wafer W. According to this embodiment of the present invention, therefore, etching processing is performed uniformly in terms of the gas flow, too.

In addition, according to this embodiment, the processing gas can be introduced from the gas supply pipe 43 provided on the upper side of the processing chamber 2a. This makes it possible to control the flow of gas with smaller particles, thereby to realize further improved uniformity of the etching processing.

As can be seen from the above, the etching equipment 1 according to this embodiment is designed to enhance the uniformity of the etching processing. For instance, in the conventional induction plasma processing apparatus, an etching rate is higher in the peripheral portion of the semiconductor wafer W, whereas in the present invention, the imbalance of the etching rate is greatly improved to enable an increase in yield.

In this embodiment, the gas supply pipe 43 is provided on the upper side of the processing chamber 2a. However, without it, if processing gas is introduced only from the gas supply port 33a of the supply path provided in the ground electrode 31, the uniformity of gas flow and consequently the uniformity of gas processing are, still, improved a lot more than the conventional apparatus.

Although this embodiment gives one supply port 33a at the supply path 33, the supply port 33a can be formed into a shower head shape. FIG. 4 illustrates a schematically sectional view of the principal part of the plasma etching equipment 81 according to another embodiment wherein the

ground electrode of the shower head is used. An insulating material 83 is provided airtightly on the upper plate of the processing housing 82 of a plasma etching equipment 81. A high frequency antenna 81 for exciting plasma is arranged on the upper surface of the insulating material 83.

A ground electrode 85 is provided through the insulating material 83 at the center of the high frequency antenna 84. The ground electrode 85 is connected directly to a GND not through a variable load circuit equipment. A hollow portion 86 is formed in the electrode 85. A plurality of supply ports 87 leading to the hollow portion 86 are formed radially or coaxially below the hollow portion 86. A supply path 88 leading to the hollow portion 86 is formed above the hollow portion 86, and the upper surface of the supply path 88 serves as a gas inlet 88a.

A first conductive supply pipe 89 is connected to the gas inlet 88a. The first supply pipe 89 is connected to a second conductive supply pipe 91 through an insulating member 90. The second supply pipe 90 is grounded and connected to processing gas supply sources 97 and 98 through valves 93 and 94 and mass flow controllers 95 and 96.

Since the principal part of the plasma etching equipment 81 has the above structure, the ground electrode 85 contributes to intensifying the central portion of the bias field as in the case of the plasma etching equipment 1 according to the first embodiment of the present invention. Following this, the etching rate of the central portion of the object, that is, semiconductor wafer W is increased, resulting in an increase in the uniformity of the surface etching as a whole.

Additionally, processing gas introduced into the processing housing 82 from the processing gas supply sources 97 and 98 is uniformly supplied from a lot of supply ports 87 formed at the ground electrode 85 to the processed surface of the semiconductor wafer W which opposes the supply ports 87. As a result, the direction of the gas flow above the semiconductor wafer W is determined and thereby the uniform gas flow is obtained. From this, too, it is clear that the uniformity of the etching processing is enhanced in the present invention. Note, the above-mentioned supply ports are not necessarily the same in diameter. They may be set such that the larger the diameter of those closer to the center, the smaller the diameter of those closer to the peripheral portions. It is also possible to make the distribution width of the supply ports 87 larger than the surface width of the object in order to supply gas more uniformly.

The third embodiment will be described with reference to FIG. 5. According to this embodiment, a dielectric upper plate 104 is provided airtightly by way of an O ring 105 above a processing housing 101 which stores a holding base 102 for holding a semiconductor wafer 103. A ground electrode 104a is provided airtightly at the center of the upper plate 104 in such a manner as to be flush with the upper plate 104. The ground electrode 104a is formed to be larger in size than the diameter of the semiconductor wafer 103. Between the upper plate 104 and an induction coil 106, an electrostatic shield 107 is provided. The induction coil 106 is connected between a high frequency power source 108 and a grounded terminal. To the grounded terminal, the ground electrode 104a of the upper plate 104 and an electrostatic shield 107 are connected. The electrostatic shield 107 comprises, as shown in FIGS. 6A and 6B, a disc-shaped shield plate provided with slits.

In a case where no electrostatic shield plate 107 is provided unlike this embodiment, it happens that when high frequency electric power is supplied from the high frequency power source 108 to the induction coil 106, a high

frequency field generated by the induction coil 106 is coupled to the ground electrode 104a. The field causes sputtering of the dielectric upper plate 104 by positive ions within plasma, following that dust, which occurs in the processing housing 101, is adhered to the semiconductor wafer 103. Contrarily, in the case of providing between the upper plate 104 and the induction coil 106, the electrostatic shield 107 set at a ground potential, the electric field generated by the induction coil 106 is shielded by the electrostatic shield 107, preventing above-mentioned sputtering from occurring.

FIG. 7 exemplifies a case of using a double-antenna structure used in this embodiment. That is, an antenna 120 comprises two ring-shaped antennas 120a and 120b which are provided coaxially or, preferably, on the same surface. Between the terminals of the outer antenna 120a, a first high frequency power source 122a is connected through a capacitor 121a which serves as a matching circuit. Between the terminals of the inner antenna 120b, a second high frequency power source 122b is connected through a capacitor 121b which serves as a matching circuit.

The first and second high frequency power sources 122a and 122b have the same frequency, e.g. 13.56 MHz, and supply first high frequency power and second high frequency power having the same phase as each other to the outer antenna 120a and the inner antenna 120b, respectively. Here, since the second high frequency power is set lower than the first high frequency power, larger amounts of current flow through the outer antenna 120a than the inner antenna 120b. A plasma generation region which is in the chamber space right below the antennas, is shifted outside, compared with the case of using a single antenna. By using a double-antenna structure, more uniform plasma density can be provided in this embodiment.

FIG. 9 illustrates another embodiment wherein a double-antenna structure as shown in FIG. 8 is utilized. According to this embodiment, the bottom and side surfaces of a chamber 115 of the plasma processing equipment are made of aluminum, and an upper plate 131 comprises a cylindrical enclosed chamber made of quartz glass. A ground electrode 131a is provided airtightly at the center of the upper plate 131.

A cylindrical support member 132 consisting of an insulating member such as ceramics or quartz, is disposed at the center of the bottom surface of the chamber 115. A disc-shaped electrode substrate 133 made of, e.g. aluminum, is provided on the support member 132. A wafer chuck 134 formed of an insulating member such as ceramics is provided on the substrate 133.

A disc-shaped paramagnetic metal 135 for electrostatic shielding, made of, e.g. aluminum, is provided on the outer wall surface of the upper plate 131 of the chamber 115. An inner high frequency coil 136 of one turn and an outer high frequency coil 137 of one turn are arranged on the paramagnetic metal 135 through an insulating member. The paramagnetic metal 135 is grounded and capacitive coupling parasitically existing between the high frequency coils and plasma is prevented by voltage applied to the inner and outer high frequency coils. The inner and outer high frequency coils 136 and 137 have the same plane structure as that of the double antennas of FIG. 7.

A non-grounded terminal of a lower power source 152 is connected through a capacitor 153 to the electrode substrate 133. Between the electrode substrate 133 and the wafer holding base 134, an electrostatic chuck electrode 154 is embedded. The electrode 154 is kept to a positive potential

by a DC power source 163. A wafer 164 is held on the wafer holding base 134.

A gas pipe 165 passes through the upper side of the chamber in an airtight manner and is connected to a shower head 166. A gas exhaust pipe 167 is provided on the lower side of the chamber 115. The lower portion of a cylindrical casing 168 is fixed to the upper side of the chamber 115, and a matching box unit 169 having a capacitor circuit for impedance matching is provided on the upper side of the casing 168. High frequency power of 13.56 MHz is supplied to the inner and outer high frequency coils 136 and 137 by way of the matching box 169.

An electromagnetic shield cylinder 170 made of aluminum or copper is provided between the inner and outer high frequency coils 136 and 137. It is provided for preventing mutual intervention of the electric field between the inner and outer high frequency coils 136 and 137. And the cylinder 137 is grounded.

Explanation will be given to the operation of the embodiment of FIG. 9.

An object, that is, semiconductor wafer 164 is held on the wafer holding base 134. The atmosphere in the chamber 115 is reduced to a predetermined degree of vacuum by way of a gas exhaust pipe 167, preparing for a state in which predetermined processing gas with a predetermined pressure and flow rate is supplied to the chamber 115 from the gas supply pipe 165.

An ON/OFF switch is turned on, and the power of 13.56 MHz, 3 kW is supplied from a high frequency power source 111 to a variable quadrature detector 112. The detector 112 divides the power of the high frequency power source 111 into two powers P1 and P2 which are supplied to a matching box 169 via a phase shifter 113. The matching box 169 supplies the powers P1 and P2 to coils 136 and 137, respectively. If high frequency current flows through the high frequency coils 136 and 137, an alternating field occurs around the coils. Most of the field passes through the center of the antennas (high frequency coils 136 and 137) in the longitudinal direction, and form a closed loop. The alternating field induces a concentric alternating electric field in the circumferential direction right under the high frequency coils 136 and 137. When electrons accelerated by the alternating fields in the circumferential direction collide with neutral particles of processing gas, gas is ionized to generate plasma. Then, ions, electrons and other active materials contained in plasma are supplied to or irradiated onto the entire surface of the semiconductor wafer 164 in a uniform manner. Thus, uniform plasma-processing is carried out to the entire surface of the wafer 164.

If it is necessary to change plasma distribution depending on the processing types, e.g. discharge processing, cleaning processing or etching processing, an optimum plasma distribution can be formed by adjusting phases of powers P1 and P2 using the phase shifter 113 in accordance with the processing types.

As explained in the embodiment, if the ground electrode 131a is arranged at the upper plate 131 and phases of powers P1 and P2 supplied to the high frequency coils 136 and 137 are changed, then the density distribution of fields induced in the chamber 115 and consequently etching processing become more uniform. As shown in the last embodiment, if the processing gas supply path is provided at the ground electrode 131a and through the path, processing gas is introduced, then the gas flow rate and consequently processing become far more uniform.

The embodiment of the present invention have been described, referring to a plasma etching apparatus. However,

the present invention can be applied to various plasma processing apparatuses such as a plasma CVD apparatus, a plasma ashing apparatus and a plasma sputtering apparatus. Also, as an object, not only a semiconductor wafer but an LCD substrate or the like can be used.

According to the present invention as described above, the induction type plasma processing apparatus, which is provided with the ground electrode, can change the field intensity distribution, making a reaction speed uniform to thereby realize uniform processing to the object. For instance, if etching processing is carried out, the present invention can compensate for a decrease in the etching rate at the center of the object, so that etching processing can be carried out to the object with uniform etching rate, whether the center or the periphery of the object.

Since the ground electrode is provided at the center of the high frequency antenna, the bias field at the center thereof can be intensified and reaction speed at the center of the object can be increased without influencing the generation of plasma. Besides, since the bias field can be changed arbitrarily and continuously, desired field intensity distribution can be easily obtained.

Since the processing gas supply port is provided at the ground electrode, the processing gas flow on the object can be orientated, for example, from the center to the periphery, and uniform processing can be given to the object. Besides, since the intensity distribution of the bias field is improved to be uniform, the processing uniformity can be improved accordingly.

Since the ground electrode is formed to be flush with the inner wall of the processing chamber, it does not affect the generation and distribution of plasma and processing uniformity is thereby improved further. Due to a plurality of supply ports provided at the ground electrode, processing gas is introduced into the processing chamber from the plural ports and the gas flow becomes more uniform consequently contributing to uniform processing. Since the ground electrode is grounded irrespective of the processing gas supply path, generated plasma and the bias field are far more stabilized and lead to more stable, uniform processing.

Moreover, since the ground electrode is grounded through the variable load circuit equipment, the bias field distribution can be arbitrarily controlled, making it possible to make finite adjustment to the detailed process. Due to the gas supply ports provided on the upper and side surfaces of the housing, processing gas is introduced into the processing chamber from two directions, i.e. upward and lateral directions. As a result, even if uneven gas flow occurs, it can be compensated to be uniform.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, representative devices, and illustrated examples shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

1. A plasma processing apparatus comprising:
 - a chamber having an upper wall in which an object is placed; gas supply means having a gas supply pipe to said object for supplying processing gas into said chamber;

a high-frequency antenna of one of a spiral type, a coiled type and a looped type, provided on at least one of inside and outside of said upper wall of said chamber to oppose said object, for ionizing processing gas supplied into said chamber for processing said object;

a high-frequency power source for supplying high-frequency power to said high-frequency antenna; and an electrode mounted on said upper wall of said chamber to oppose said object on a center of said high-frequency antenna and to be insulated from said high-frequency antenna and set at a reference potential, for providing a uniform electric field above said object, and wherein said gas supply means includes at least one gas supply path provided in said electrode and communicating with said gas supply pipe.

2. A plasma processing apparatus according to claim 1, wherein said upper wall of said chamber is formed of a dielectric plate.

3. A plasma processing apparatus according to claim 2, wherein said electrode is connected to a grounding electrode.

4. A plasma processing apparatus according to claim 3, further comprising a reference potential adjustment circuit, connected between said electrode and said grounding electrode, for controlling potential of said electrode.

5. A plasma processing apparatus according to claim 2, wherein said electrode is provided on said dielectric plate to be flush with said dielectric plate.

6. A plasma processing apparatus according to claim 2, further comprising an electrostatic shield plate interposed between said antenna and said dielectric plate.

7. A plasma processing apparatus according to claim 1, wherein said gas supply pipe has a supply port communicating with said gas supply path of to introduce said processing gas into a central portion of said object.

8. A plasma processing apparatus according to claim 1, wherein said gas supply means has a hollow portion communicating with said gas supply path and a plurality of supply ports communicating with said hollow portion to introduce said processing gas into a central portion of said object.

9. A plasma processing apparatus according to claim 1, wherein said antenna comprises one of a spiral antenna, a coiled antenna and a looped antenna.

10. A plasma processing apparatus according to claim 1, wherein said antenna comprises a plurality of ring-shaped antenna elements which are arranged coaxially, and said high-frequency power source supplies two high-frequency electric powers, which are the same in frequency and phase, to said antenna elements, respectively.

11. A plasma processing apparatus according to claim 10, wherein said antenna elements have an inner antenna element and an outer antenna element, and said high-frequency power source supplies larger amounts of a high frequency current to said outer antenna than said inner antenna.

* * * * *



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Snyder

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[54] **CONDENSATION FREE NOZZLE**

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[73] **Assignee:** Praxair Technology, Inc., Danbury, Conn.

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 239/DIG. 19; 239/553

[58] **Field of Search** 431/349, 187,
 431/8; 239/DIG. 19, 553, 558

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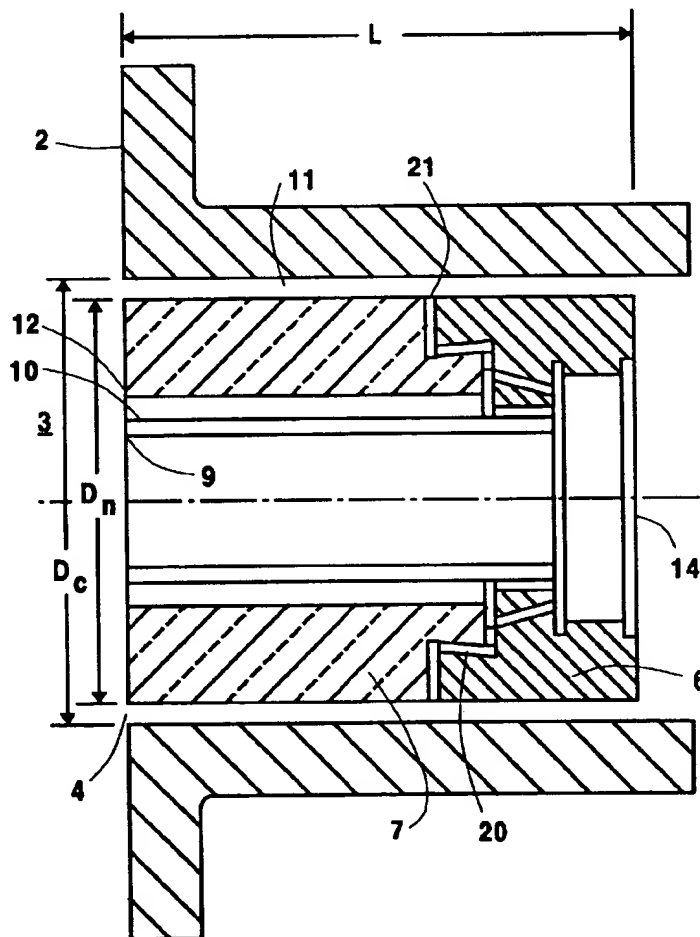
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Attorney, Agent, or Firm—Stanley Ktorides

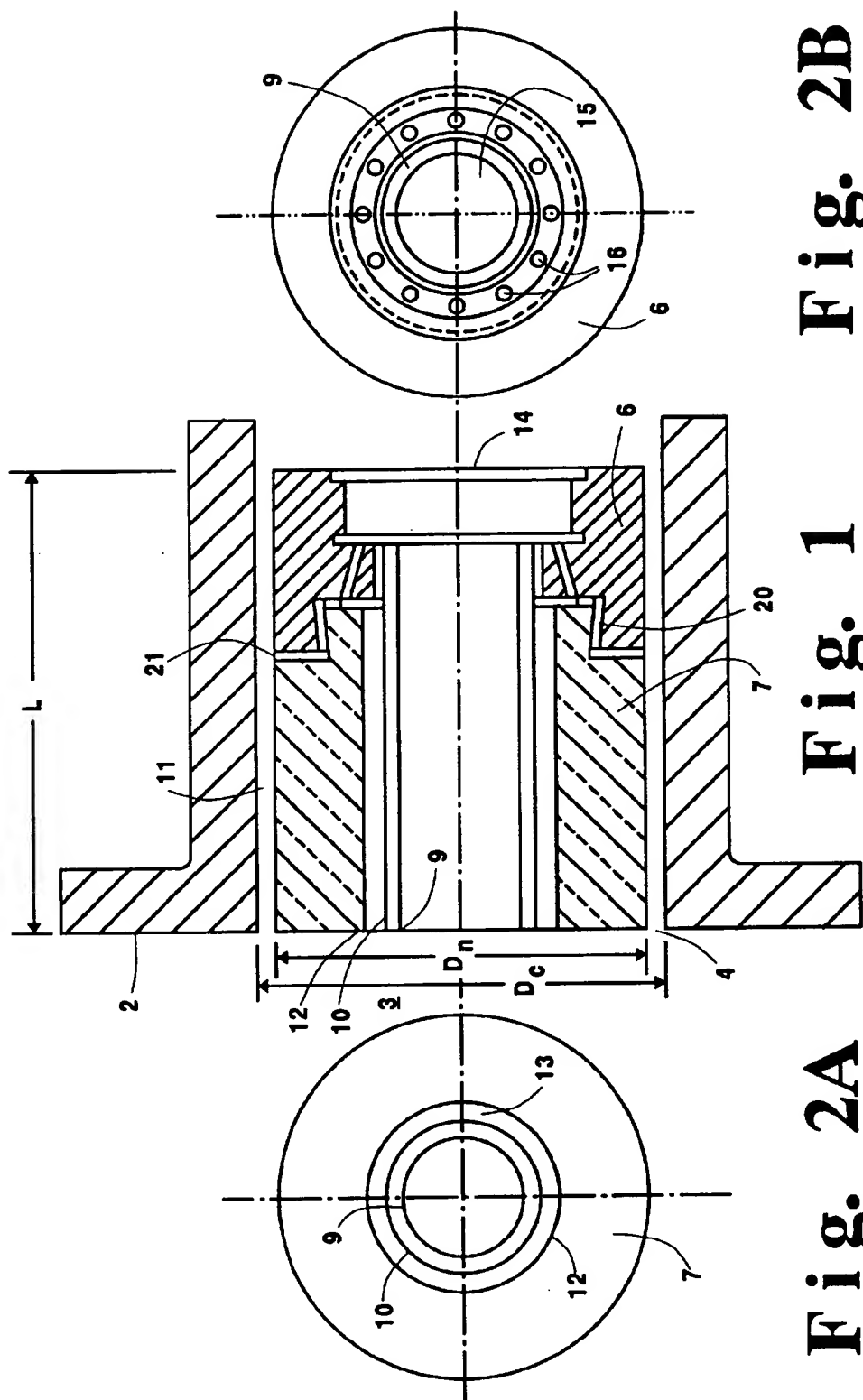
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ABSTRACT

A nozzle which includes a nozzle body, a central tube contained within the nozzle body for a flow of gas at a temperature less than the temperature of the nozzle body, and an annular passage, located between the nozzle body and central tube, for a flow of gas at a velocity less than the flow of gas in the central tube and less than about 100 ft/sec. enabling the nozzle to operate at elevated temperatures and avoid condensation thereon of vapors from the surrounding gas environment.

8 Claims, 2 Drawing Sheets





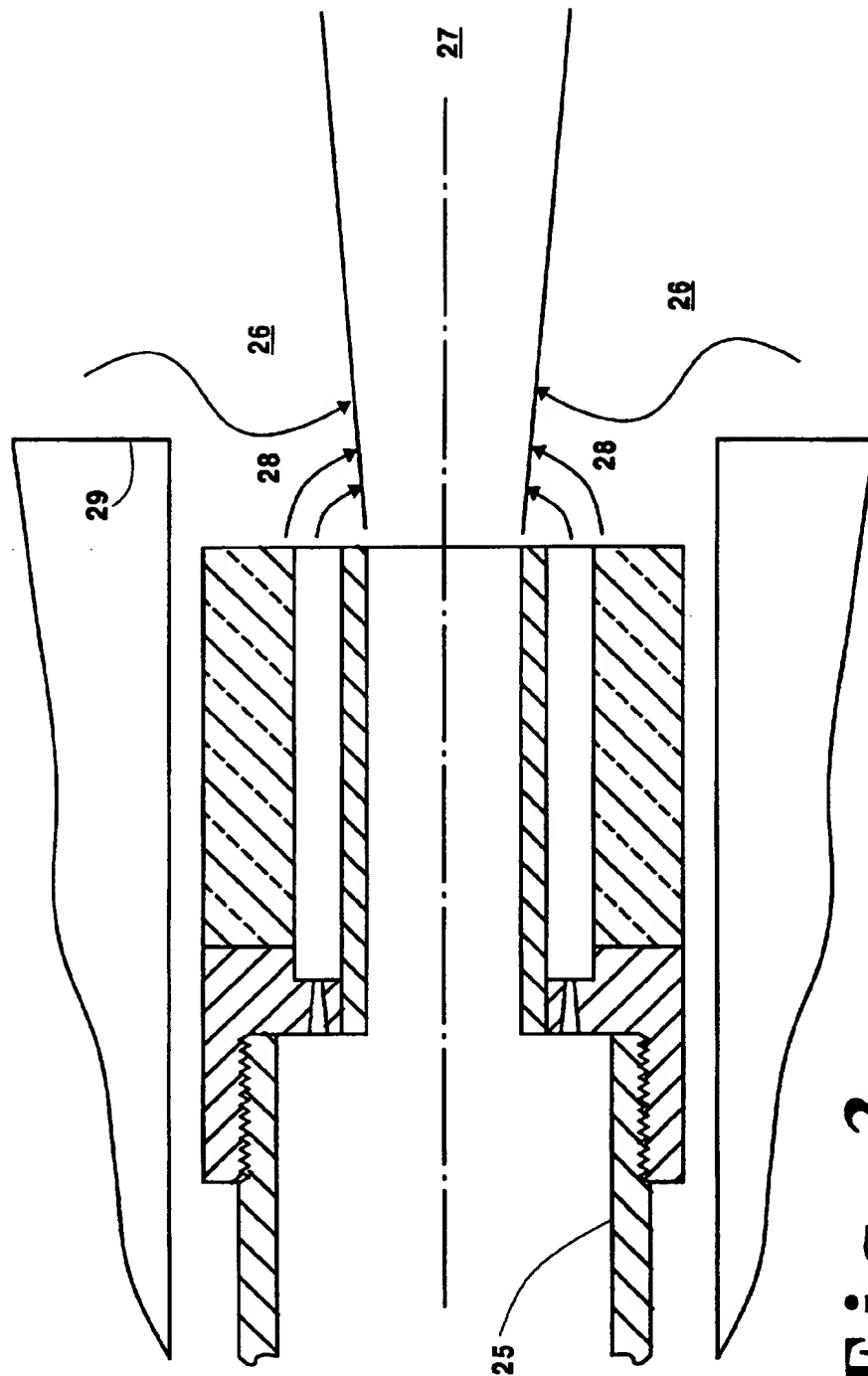


Fig. 3

CONDENSATION FREE NOZZLE

FIELD OF THE INVENTION

The present invention relates generally to nozzles, more particularly to nozzles useful for the injection of gases into a combustion zone.

BACKGROUND ART

Advances in combustion technology have employed the use of high velocity gas injection into a combustion zone to carry out combustion with reduced nitrogen oxides (NO_x) generation. Nozzles with relatively small diameters are employed in order to achieve the high velocities. The high gas velocities cause furnace gases to be aspirated or entrained into the high velocity gas which has a dampening effect on NO_x generation.

A problem with high velocity gas injection into a combustion zone is that the furnace gases, which may comprise particulate matter and condensable vapors, cause the nozzles, which have small openings to begin with, to foul, plug or corrode easily as the furnace gases are aspirated or entrained into the high velocity gas exiting the nozzle. The furnace gases also tend to be quite hot, on the order of 1000°F ., or more, which exacerbates the fouling and corrosion problem. This problem becomes particularly severe when the furnace temperature exceeds 2200°F . The maximum service temperatures of common high temperature alloys are generally less than 2200°F ., for fuel-fired furnace atmospheres. Some noble metals such as platinum can withstand higher temperatures, but the cost becomes excessive.

One way of dealing with this problem has been to provide a large amount of water cooling to the nozzle so as to prevent high temperature corrosion or melting. However, a water cooling system is complex to operate, costly, and does not address the fouling problem where the furnace atmosphere has a high particulate content. Moreover, water cooling can escalate the corrosion and fouling problems when the furnace atmosphere contains condensable vapors.

Ceramic lances have been proposed as a solution to the fouling problem in high velocity gas injection. However, presently available ceramic lances are not suitable for industrial scale operations because of corrosion and cracking due to thermal and other stresses.

It is known that temperature effects on a nozzle may be ameliorated by recessing the nozzle in a cavity communicating with a combustion zone. However, a relatively large recess is required to achieve a significant beneficial effect. With high velocity gas injection, such a large recess may be detrimental because a large amount of corrosive furnace gas may be drawn into the cavity. Furthermore, this results in a reduction in the gas jet velocity. Thus, while the nozzle avoids temperature induced damage, this is offset by increased damage caused by contact with corrosive furnace gas drawn into the cavity.

A recurring problem in refractory tipped oxygen or fuel injectors in glass furnaces can be the accumulation of condensed materials on the tip of the nozzle which form a narrow tube-like structure around the jet extending into the furnace. These growths, over time, can distort the jet and cause undesirable combustion conditions to exist in the furnace which, in turn, can damage the furnace refractory, cause off ratio burner operation, or upset the glass quality.

One previous approach, described in U.S. Pat. No. 5,266, 025, purged the area around the nozzle with clean gas, e.g. oxygen. This usually required passing a large percentage of

the gas (30%–50%) around the nozzle to prevent the furnace atmosphere from contacting the nozzle. In practice, however, because the concentricity of the nozzle within the annulus is important to achieve this protection, it is generally difficult to achieve. Also, by shifting a large percentage of gas to the annulus, the NO_x performance of the burner may be compromised (i.e., high NO_x can form) or higher oxygen pressure may be required to increase the velocity of the center jet.

Another previous approach involved building the nozzle from a porous material to have clean gas emanating from any surface which could possibly accumulate deposits. The design of such a nozzle, however, is fairly complicated, its life in the furnace is questionable, and it produces slightly higher NO_x than a conventional refractory-tipped nozzle.

A further approach involved lengthening the refractory section of the nozzle to elevate the surface temperature of the nozzle. Also, along these lines, the existing nozzles were inserted further into the furnace resulting in higher surface temperatures on the nozzle. These techniques alleviated the problem, but did not eliminate it, or created other problems such as overheating of the metallic components of the lance.

In light of the foregoing, there is a need for a nozzle that overcomes the disadvantages of the related art.

SUMMARY OF THE INVENTION

Accordingly, the present invention is directed to a nozzle which may be employed in a high velocity gas injection system and substantially obviates one or more of the problems due to the limitations and disadvantages of the related art.

An additional object of the present invention is to prevent condensation on nozzle surfaces, for instance by preventing cold nozzle surfaces from occurring instead of altering the conditions around the nozzle (i.e., shrouding, purging, etc.).

Additional features and advantages of the present invention will be set forth in part in the description which follows, and in part will be apparent from the description, or may be learned by practice of the present invention. The objectives and other advantages of the present invention will be realized and attained by means of the elements and combinations particularly pointed out in the written description and appended claims.

To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and broadly described herein, the nozzle of the present invention has a nozzle body, a central tube, and an annular passage. The central tube is contained within the nozzle body and is for a flow of a gas. The annular passage, located between the nozzle body and the central tube, is substantially flush with the end of the central tube, and is also for a flow of a gas. The velocity of the gas flowing through this passage is less than the velocity of the gas flowing through the central tube and is less than about 100 ft/sec. The wall thickness of the central tube is less than or equal to the radial width of the annular passage (i.e., gap of the annulus).

Another aspect of the present invention is a gas injection system comprising a cavity within a wall of a combustion zone and having an opening communicating with the combustion zone and the above-described nozzle in the cavity.

An additional aspect of the present invention is a nozzle for injecting gas into a combustion chamber. The nozzle has an annular body having a central bore with an inlet end and an outlet end. The nozzle also has a tubular member positioned in the central bore for receiving a first gas at the inlet

end and ejecting the first gas at an outlet end. The tubular member has an outer surface defining an annular passage extending between the inlet and outlet ends for passing a second gas received at the inlet end. Also, the nozzle has means for reducing the transfer of heat in the radial direction between the annular body and the first gas contained in the tubular member. The first gas and second gas can be from the same or different gas sources.

A further aspect of the present invention is a method of minimizing or preventing condensation on a nozzle surface of a nozzle used for injecting gas into a combustion chamber. The method includes passing a first gas at a first rate of flow through a tubular member located within a nozzle body and forming an annular passage, and passing a second gas at a second flow rate through the annular passage that is substantially flush with the end of the tubular member. The second rate of flow of the second gas is substantially less than the first rate of flow and less than about 100 ft/sec. The tubular member has a thickness less than or equal to the radial width of the annular passage, and along with the second rate of flow, impedes the transfer of heat between the nozzle and the gas at the first flow rate.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are intended to provide further explanation of the present invention, as claimed.

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the present invention and together with the description, serve to explain the principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view partly in cross-section of a preferred embodiment of the nozzle and gas injection system of the present invention.

FIG. 2A is a view of the exit end of the nozzle and gas injection system of FIG. 1.

FIG. 2B is a view of the inlet end of the nozzle and gas injection system of FIG. 1.

FIG. 3 is another view partly in cross-section of another preferred embodiment of the nozzle and gas injection system of the present invention.

DETAILED DESCRIPTION

As used herein, the term "nozzle" means a device through which either gaseous oxidant or gaseous combustible matter or a premixed mixture of oxidant and fuel is injected into a cavity or a combustion zone.

As used herein, the term "ceramic" means a non-metallic material which can withstand a temperature greater than 2200° F. Ceramics typically are refractory materials comprising oxides, carbides, or nitrides.

The present invention minimizes or prevents condensation on a surface of a nozzle, for instance, used for injecting gas into a combustion chamber. This is primarily accomplished by passing a first gas at a first rate of flow through a tubular member located within a nozzle body and forming an annular passage, and also passing a second gas at a second rate of flow through the annular passage. The tubular member has a thickness less than or equal to the radial width of the annular passage. The second gas through the annular passage is at a second rate of flow substantially less than the first rate of flow and less than about 100 ft/sec. This difference in flow rate impedes the transfer of heat in the

radial direction. Or, in other words, it impedes the transfer of heat between the nozzle and the gas at the first flow rate. The first and second gas can be from the same or different gas source.

Referring to FIGS. 1, 2A and 2B, refractory wall 2 borders combustion zone 3 wherein there is contained a furnace atmosphere comprising furnace gases such as, for example, carbon dioxide, water vapor, nitrogen and/or oxygen. The furnace atmosphere is generally at an elevated temperature typically exceeding 2000° F., and usually within the range of from 2000° to 3500° F. The furnace atmosphere may also contain particulate matter, such as glass batch materials or ash from coal combustion, and/or condensable vapors such as sodium species or acid vapors.

Within refractory wall 2 there is provided cavity 11 which communicates with combustion zone 3 at opening 4. Generally, opening 4 will have a diameter, denominated in FIG. 1 as D_o , within the range of from 1.0 to 10 inches.

In accordance with the present invention, the nozzle for injecting a gas has an annular body. This annular body has a central bore having an inlet end and an outlet end. A tubular member 9 is positioned in the central bore and has an outer surface 10 defining an annular passage 13 (i.e., annulus). This annular passage 13 extends between the inlet and outlet ends and is substantially flush with the outlet end of the annular body and the tubular member 9. The nozzle also contains means for reducing the transfer of heat in the radial direction between the annular body and the gas contained in the tubular member. The presence of the low velocity gas in the annular passage limits the heat transfer.

In more detail, the nozzle has a nozzle body 6, 7 that contains a central tube 9 and an annular passage 13 (i.e., an annular body having a central bore and a tubular member, having an outer surface defining an annular passage, positioned in the central bore). The central tube 9 is for a flow of a gas. The temperature of the gas flowing through the central tube 9 is less than the temperature of the nozzle body.

Further, the annular passage 13 (i.e., annulus) is located between the nozzle body 6, 7 and the central tube 9. The annular passage 13 is for a flow of gas having a velocity less than the velocity of the gas flowing through the central tube and has a velocity less than about 100 ft/sec.

The nozzle body 6, 7 can be fabricated from any material commonly used in combustion technology which is able to withstand elevated temperatures, which typically exceed 2000° F. Preferably the nozzle body is a composite piece. The nozzle body can have a $1\frac{1}{2}$ " inner diameter and an outer diameter of $2\frac{7}{8}$ ".

Preferably, the nozzle body is constructed of a heavy nozzle wall. The thickness of the nozzle body from a point beginning at the outer edge of the annular passage to the edge of the nozzle body is preferably about $\frac{1}{2}$ " to about $1\frac{1}{2}$ ", more preferably from about $\frac{3}{4}$ " to about 1". This preferred heavier nozzle wall protects the central tube from damage by impact during the insertion or removal of the nozzle in a furnace. The heavier nozzle wall also reduces the susceptibility to thermal shock.

Furthermore, any adjustments necessary to the nozzle can be made without any fear of damage to the parts of the nozzle.

The nozzle body preferably has a back piece and a front piece and has an axial length denominated in FIG. 1 by L. The L/D_n can be from 0.75 to 2.5, wherein D_n is the diameter of the nozzle body. Back piece 6 can comprise from about 10 to about 60% of the nozzle axial length and front piece 7 comprises from about 40 to about 90% of the nozzle axial

length measured on the outer side of the nozzle body. Preferably, the nozzle will have an axial length within the range of from 0.5 to 2 times the diameter of opening 4. Generally, this will result in a nozzle having an axial length within the range of from 1 to 5 inches. Also, the opening in the cavity is usually minimized so that $D_c = D_n + 0.25"$.

Back piece 6 preferably comprises a metal such as stainless steel, cast iron, other steels and other high temperature alloys having maximum surface temperatures, preferably within the range of from 1500° F. to about 2200° F. Other suitable materials can be used.

Front piece 7 preferably comprises a ceramic such as refractory materials comprising alumina, silica, zirconium, magnesium, or silicon carbide. The preferred ceramic material for glass furnace applications is alumina-zirconia-silicate refractory.

The maximum surface temperatures of ceramics are typically between 2000° F. and 4000° F. A ceramic material normally used for the hot side of a furnace wall will generally be useful in the practice of this invention.

The central tube (or tubular member) 9 can be made of the same material as the front piece of the nozzle body, but is preferably a ceramic tube. As an example, the ceramic tube can have an inner diameter of 1" and an outer diameter of 1½". Preferably, besides being a ceramic tube, the central tube is a thin walled tube. The thickness of the central tube is less than or equal to the radial width of the annular passage or gap. Generally, the thickness of the ceramic tube wall is preferably from about ¼" to about ¾", more preferably from about ⅛" to about ⅜". The material of the central tube can be any high temperature refractory material that is compatible with the temperature levels in a furnace and the gases being injected into a furnace. A preferred material is an alumina tube. Other materials that can be used for the central tube include, but are not limited to, mullite, quartz, silicon carbide, or molybdenum disilicide.

Typically, the length of the central tube is from about 1.5 d to about 4 d, more preferably from about 1.5 d to about 1.6 d, wherein d is the inner diameter of the central tube. This preferred length minimizes the pressure drop of the gas emanating from the nozzle and entering the combustion zone.

The difference between the outer diameter of the central tube 9 and the inner diameter at 12 of the nozzle body opening generally forming the nozzle body defines twice the radial width of the annular passage or the annulus gap 13. Preferably, this gap is less than ¾"; more preferably from about ⅛" to about ⅜", most preferably is about ⅛" in thickness. When a gas enters the central tube and annular passage, the central tube's diameter preferably permits the flow of gas at a volume greater than the volume of gas flowing through the annular passage.

Though not necessary, generally the gas entering the central tube and the gas entering the annular passage are from the same gas source or supply. Generally, this gas-supply may be an oxidant such as oxygen, oxygen-enriched air, or technically pure oxygen, or may be fuel which is any gas which contains combustibles and which may combust in the combustion zone, or may be a premixture of oxidants and fuel. Such fuels include, but are not limited to, natural gas, vaporized liquid fuel, coke oven gas, propane, hydrogen, and methane.

The present invention will find particular utility with high velocity gases wherein the gas is ejected out the central tube and annular passage wherein the velocity of the gas exiting the central tube preferably exceeds about 150 feet per

second and can reach velocities up to 1000 feet per second or more. More preferably, the velocity of the gas exiting the central tube is from about 185 feet/second to about 400 feet/second. The velocity of the gas exiting the annular passage is typically from about 10 feet/second to about 50 feet/second.

In general, the majority of the gas supplied to the nozzle enters the central tube and the remaining amount of gas enters the annular passage. Preferably, from about 80% by volume to about 95% by volume of the gas entering the nozzle from the gas source enters the central tube, more preferably about 90% by volume of the gas enters the central tube while the remaining amount, preferably about 10% by volume, enters the annular passage from the gas source.

Back piece 6 communicates with a gas supply tube (shown in FIG. 3 as 25). In particular, the annular passage and central tube communicate with an inlet section 14. As shown in FIG. 2B, this inlet section has a central opening 15 and a plurality of openings 16 surrounding the central opening 15. The central opening communicates with the central tube and the plurality of openings communicates with the annular passage. Generally, the plurality of openings is from about 4 to about 24 equally spaced openings, each having a diameter such that the total cross-sectional area of all the openings is from about 5 to 15 percent, preferably about 10% of the total area of the openings plus the central tube opening. The plurality of openings enable the attainment of the requisite low velocity, especially from the same gas source as that of the central tube fluid, which cannot be attained with a conventional thin annular opening while still maintaining the defined low relative gas flow.

Generally, the annular passage has a length sufficient so that the velocity of the gas entering from the inlet section through the plurality of openings obtains a substantial uniform velocity in the annular passage prior to exiting the passage and entering the combustion zone. Preferably, the length of the annular passage is from about 1" to about 3".

As shown in FIG. 1, the inlet section 14 also communicates with the inner diameter of the back piece 6. Preferably, the inlet section 14 is comprised of a pipe and is attached to the nozzle body as shown in FIG. 1 by welding, brazing, or threading. Back piece 6 to front piece 7 can be adjoined by means of a reverse taper joint. Fiber ceramic gaskets 21 are used against the back piece and front piece to allow the front piece room to expand into the reverse taper joint. A reverse taper joint-gap 20 is filled with refractory ceramic cement similar to the way brick mortar fills the gap between two bricks. Small holes can be used to deliver refractory ceramic cement to joint-gap 20 which is circumferential. Other means of adjoining the front piece to the back piece include mechanical locking.

Referring to FIG. 3, the annular flow 28 provides a shielding between the central tube which may be cold and the furnace gases 26 in addition to its heat transfer effects. These effects are especially seen when the central tube is of a thin walled construction since thin walls do not require as much gas to blanket their edges and hence can tolerate being slightly eccentric in the hole. Also, due to the entrainment of gas 26 into gas jet 27 exiting the central tube, gas 28 flowing through the annulus, being of low momentum, will be preferentially pulled into jet 27 thus ensuring adequate blanketing of the central tube. Preferably, the nozzle of the present invention is either flush with the internal wall of the furnace 29 or slightly recessed (i.e., recessed about ½D, where D is the diameter of the opening of the cavity in the furnace wall). However, if recessed in a cavity, other sur-

faces in the cavity may be low enough in temperature to nucleate condensation. Thus, if the nozzle of the present invention is recessed, bulk cavity purging techniques could be required especially if the nozzle is significantly recessed in the cavity.

Preferably, the flow of the gas through the central tube and the flow of the gas through the annular passage are essentially parallel, i.e. coaxial. However, it is within the bounds of the present invention to configure the nozzle such that the flow of the gas through the annular passage converges into the flow of the gas through the central tube.

The subject invention uses the annular flow to minimize the heat transfer between the cold gas flowing through the nozzle and the nozzle itself. This results in elevated nozzle temperatures and hence no condensation onto the nozzle. Although extending the length of the nozzle also creates elevated nozzle temperatures, it only addresses the axial flow of heat and not the more important radial flow of heat from the nozzle inside diameter to the cold jet. The fact that the deposits on the nozzle form as long tubes attached at the nozzle exit shows that the surface adjacent to the gas flow is the coldest section and the nucleation point of the condensation.

The present invention minimizes the heat transfer from the hole or orifice from which the gas is exiting. Heat transfer analysis provides an example of the potential effectiveness of the present invention. The convective heat transfer coefficient in a pipe is a function of velocity of the gas. Keeping all other parameters constant, changing the velocity of the gas by a factor of 5, from 250 feet/second to 50 feet/second, would drop the convective heat transfer coefficient by 3.62. Using a heat balance equation in which the heat radiated from the furnace to the nozzle equals what is convected away by the flowing gas, the change in nozzle temperature resulting from this invention can be approximated:

$$Q_{\text{rad}} = Q_{\text{conv}} = A \Delta(T_{\text{furn}} - T_{\text{nozz}}) = hA(T_{\text{nozz}} - T_{\text{gas}})$$

After combining constants, the two equations become:

$$Co(T_{\text{furn}} - T_{\text{nozz}}) = h(T_{\text{nozz}} - T_{\text{gas}})$$

wherein T_{furn} is the temperature in the furnace; T_{nozz} is the temperature of the nozzle adjacent the furnace; and T_{gas} is the temperature of the gas flowing through the nozzle, h is the convective heat transfer coefficient, and Co is a constant.

By selecting initial conditions of temperature and heat transfer coefficient, the constant Co can be determined (e.g., at $T_{\text{furn}}=2800^{\circ}\text{F}$, $T_{\text{gas}}=80^{\circ}\text{F}$, and $T_{\text{nozz}}=1200^{\circ}\text{F}$, and $h=3.62$ the constant Co becomes 4×10^{-11}). By changing the heat transfer coefficient to 1 (equivalent to reducing the velocity by a factor of 5), a new nozzle temperature (T_{nozz}) is calculated as 2274°F . This calculation demonstrates the utility of the present invention by showing the magnitude of the achievable temperature difference with the nozzle of the present invention.

Another factor contributing to the success of the present invention is the small volume of gas flowing through the annular passage that has a small heat capacity. Thus, this gas in the annular passage increases in temperature more readily than the larger volume of gas in the central tube. This warmer gas in the annular passage again minimizes the heat transfer from the wall of the nozzle body to the gas by decreasing the temperature difference between adjacent materials.

The present invention will be further clarified by the following examples, which are intended to be purely exemplary of the invention.

A gas injection system was constructed using nozzles of the present invention using the preferred embodiments described earlier and illustrated in FIG. 1. In particular, the nozzle comprised a central refractory tube which carried 90% of the oxygen generally at a high velocity of about 250–400 ft/sec. The tube was located within the refractory tip nozzle such that an annulus was formed between the refractory central tube and the nozzle body. The remaining ten percent of the oxygen was passed through this cavity at a velocity of about 10–50 ft/sec. The flow split between the two cavities was achieved by the difference in area between the inlet sections of the two passages. The annular passage, supplied by 12 holes, had enough length to ensure that velocity in that passage was uniform when it reached the exit of the passage. The ceramic tube had an outer diameter of $1\frac{1}{4}$ " and an inner diameter of 1" and was placed in a $1\frac{1}{2}$ " diameter ceramic nozzle. This produced a $\frac{1}{8}$ " annulus gap. The outer diameter of the nozzle was $2\frac{1}{4}$ ". When operated at 4230 scfh, the velocity of the main jet was 194 ft/sec and that of the annulus was 31 ft/sec. After six weeks of combustion being carried out within the combustion zone of an operating glass furnace, no fouling of the nozzle occurred.

Other embodiments of the present invention will be apparent to those skilled in the art from consideration of the specification and practice of the present invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the present invention being indicated by the following claims.

What is claimed is:

1. A nozzle for injecting gas into a combustion chamber, comprising:

an annular body having a central bore with an inlet end and an outlet end,

a ceramic tubular member positioned in the central bore for receiving a first gas stream at the inlet end and discharging the first gas stream at an outlet end, said tubular member having an outer surface defining an annular passage between the annular body and the tubular member, said annular passage having a radial width extending between the inlet end and outlet end for passing a second gas stream received at the inlet end, wherein said tubular member has a wall thickness less than or equal to the radial width of the annular passage;

means connecting said central bore and said annular passage to a common source of gas, means for discharging a flow of gas from said annular passage at a velocity substantially less than that discharged from said central core for reducing the transfer of heat between the annular body and the gas contained in the tubular member.

2. A nozzle comprising:

an annular nozzle body;

a ceramic central tube, contained within said nozzle body, for flowing gas; and

an annular passage, located between said nozzle body and said central tube and said annular nozzle body being substantially flush with the end of the central tube said annular passage and said central tube being connected to a common gas source, and means associated with said annular passage for flowing gas at a velocity less than the velocity of gas in said central tube and less than about 100 ft/sec, said central tube having a wall thickness less than or equal to the radial width of the annular passage.

3. The nozzle of claim 2, wherein said means associated with said annular passage includes an inlet section having a central opening and a plurality of openings surrounding said central opening, and wherein said central opening communicates with said central tube and said plurality of openings communicates with said annular passage. 5

4. The nozzle of claim 3, wherein said plurality of openings is from about 4 to about 24 equally spaced openings having a total area of from about 5 to 15 percent of the total area of said central opening plus said equally spaced openings. 10

5. A method for preventing condensation on a surface of a nozzle used for injecting gas into a combustion chamber, comprising:

passing from a common gas source gas at a first rate of flow through a ceramic tubular member located within an annular nozzle body; 15

passing gas through an annular passage having a radial width, located between said nozzle body and tubular member, said annular body terminating substantially flush with the end of the tubular member, at a second 20

rate of flow less than the first rate of flow and less than about 100 ft/sec to impede the transfer of heat between the nozzle and the gas at the first rate of flow, wherein said tubular member has a thickness less than or equal to the radial width of the annular passage.

6. The method of claim 5, wherein from about 80% by volume to about 95% by volume of gas from said common gas source enters said tubular member and the remaining volume of gas from said gas source enters said annular passage.

7. The method of claim 5, wherein said second rate of flow in said annular passage is from about 10 ft/second to about 50 ft/second.

8. The method of claim 5, wherein said first rate of flow in said tubular member has a velocity of from about 185 ft/second to about 400 ft/second and said second rate of flow in said annular passage has a velocity of from about 10 ft/second to about 50 ft/second.

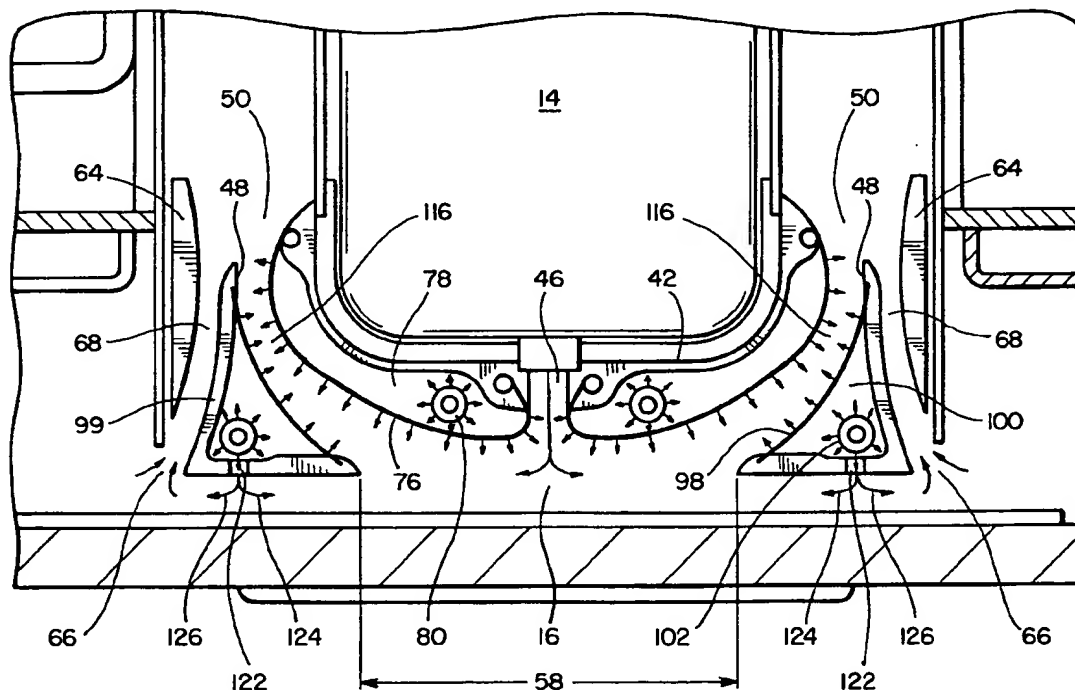
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US005849088A

United States Patent [19]**DeDontney et al.**[11] **Patent Number:** **5,849,088**[45] **Date of Patent:** **Dec. 15, 1998**[54] **FREE FLOATING SHIELD**[75] **Inventors:** Jay Brian DeDontney, Santa Cruz;
Lawrence Duane Bartholomew,
Felton, both of Calif.[73] **Assignee:** Watkins-Johnson Company, Palo Alto,
Calif.[21] **Appl. No.:** 8,024[22] **Filed:** Jan. 16, 1998[51] **Int. Cl.⁶** C23C 16/00[52] **U.S. Cl.** 118/719; 118/725; 118/729[58] **Field of Search** 118/715, 719,
118/725, 729[56] **References Cited****U.S. PATENT DOCUMENTS**4,834,020 5/1989 Bartholomew 118/729
5,487,784 1/1996 Ellis 118/729**OTHER PUBLICATIONS**Watkins-Johnson "Injector Vent Assemblies",
WJ-TEOS999 APCVD System, Physical & Functional, pp.
4-78, 4-79, 4-68.*Primary Examiner*—Richard Bueker
Attorney, Agent, or Firm—Flehr Hohbach Test Albritton &
Herbert, LLP[57] **ABSTRACT**

A protective shield and an atmospheric pressure chemical vapor deposition system including a protective shield. The shield includes a frame assembly including a pair of spaced end walls and a pair of side walls extending between and mounted to the end walls, and a plurality of shield bodies carried by the frame assembly. Each of the shield bodies includes a base, a perforated sheet carried by the base, a plenum between the base and the perforated sheet, and a gas delivery device for delivering an inert gas to the plenum at a flow rate such that the gas diffuses through the perforated sheet. The chemical vapor deposition system includes a plurality of processing chambers, a conveyor for transporting substrates through the processing chambers, buffer chambers isolating the processing chambers from the rest of the process path all enclosed within a muffle. A protective shield mounted in the processing chambers includes injector shield bodies positioned adjacent the injector and shunt shield bodies spaced from the injector shield bodies, an inlet port between the injector shield bodies, and an outlet port between the shunt shield bodies for the flow of reagents through the protective shield. The shunt shield bodies each include a plenum filled with an inert gas and a bottom outlet port coupled to the plenum for delivering a supply of inert gas below the protective shield to form buffer barriers on opposite sides of the injection ports. The shield body captures the perforated sheets and shield bodies such that the sheets and shield body base can freely expand and contract relative to each other and the end walls under varying temperature conditions, maintaining the precise chamber geometry control required for CVD processing.

29 Claims, 9 Drawing Sheets

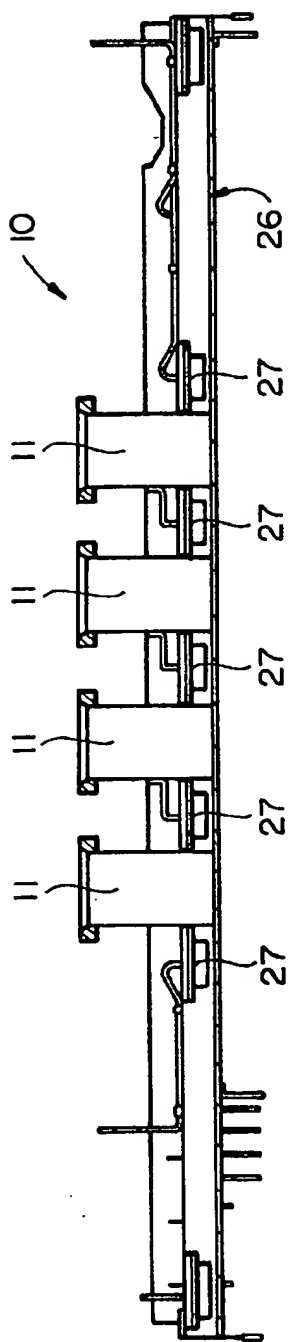


FIG. 1
(PRIOR ART)

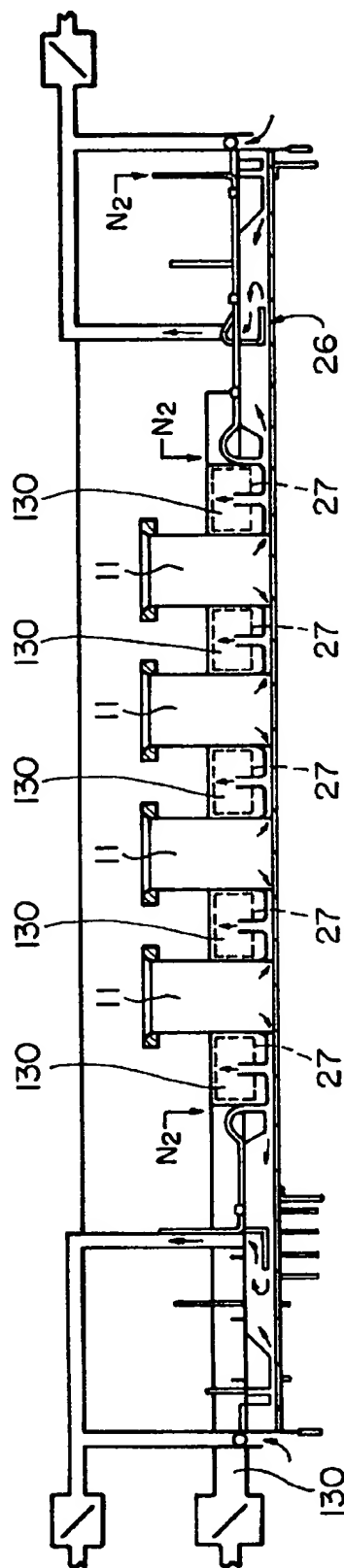


FIG. 15

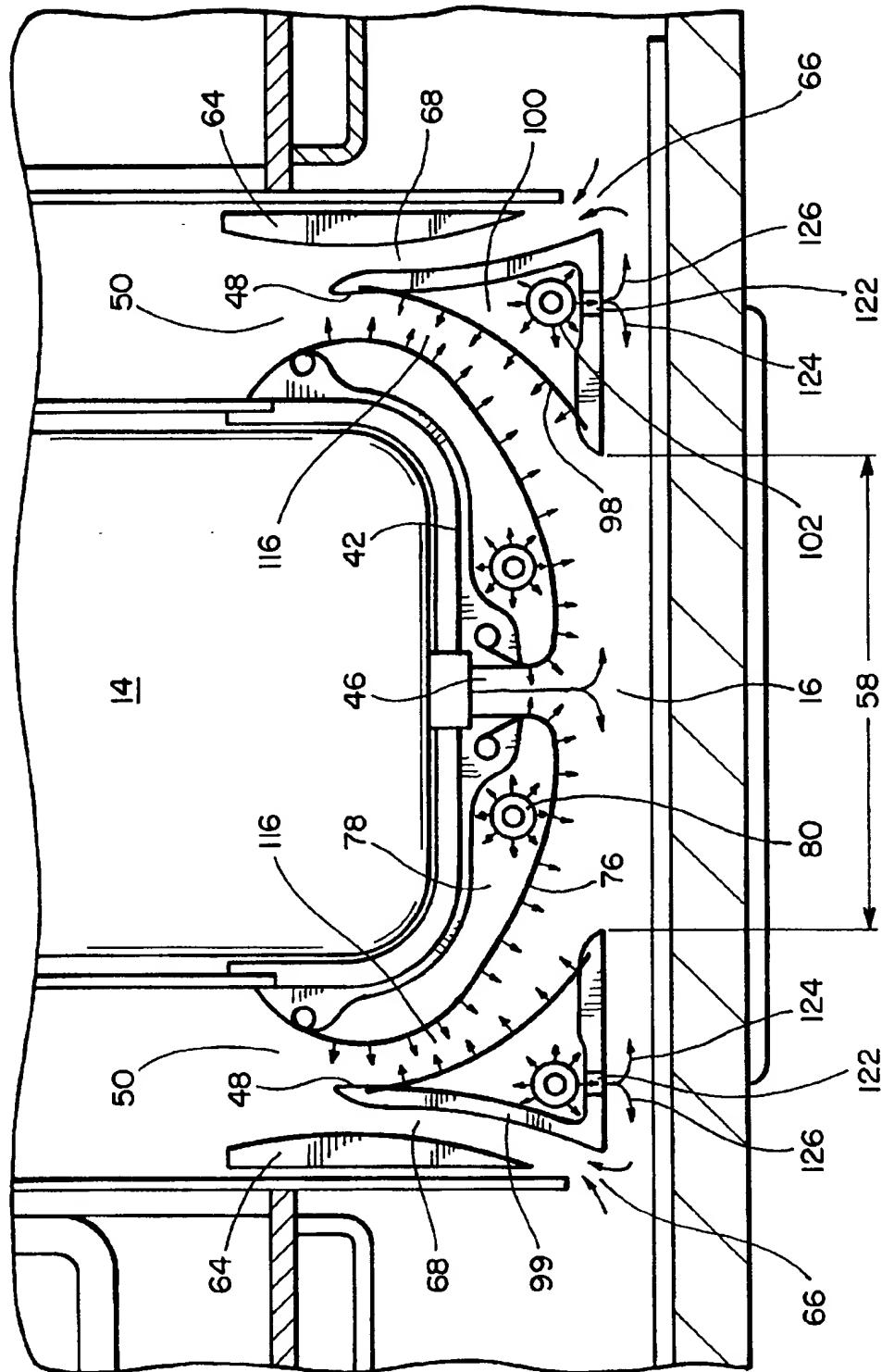
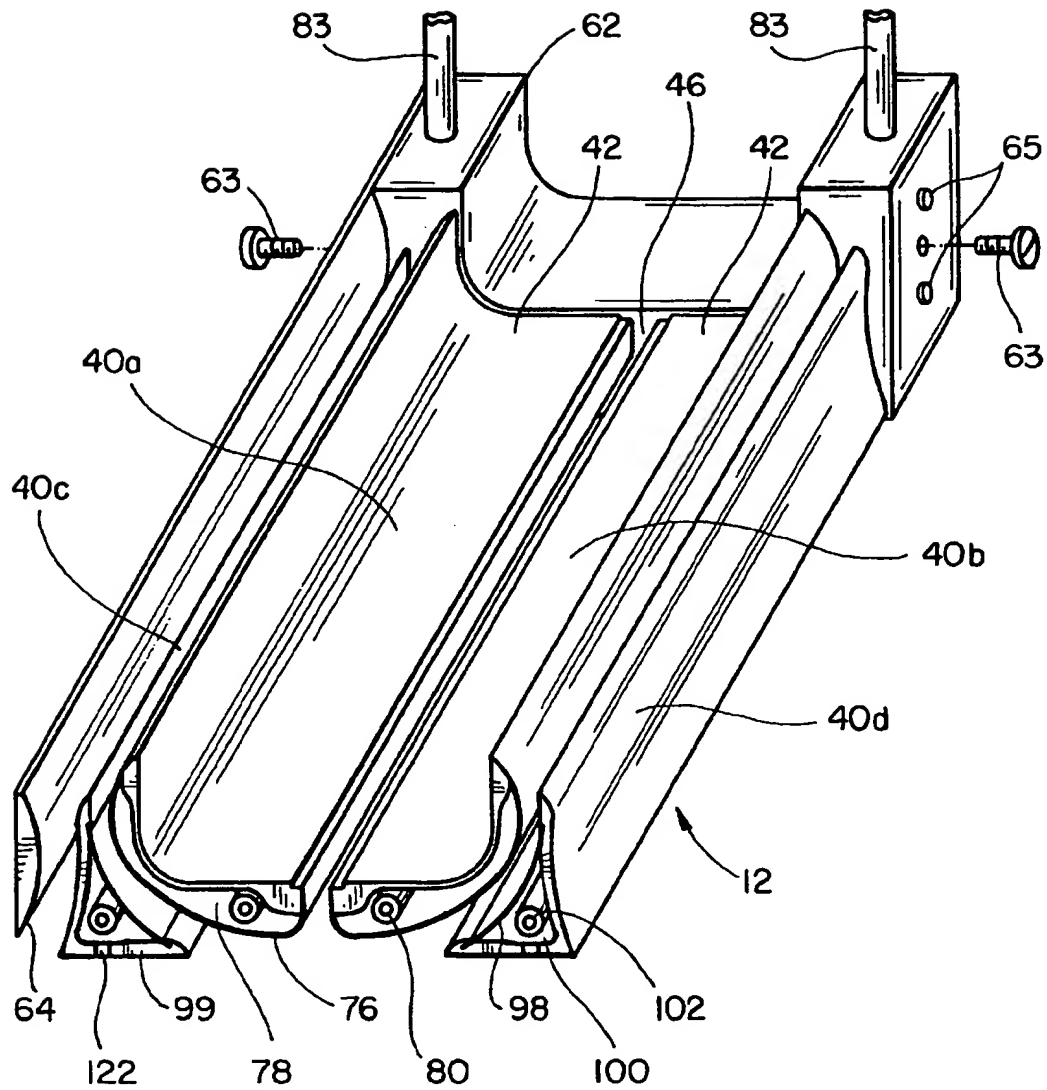
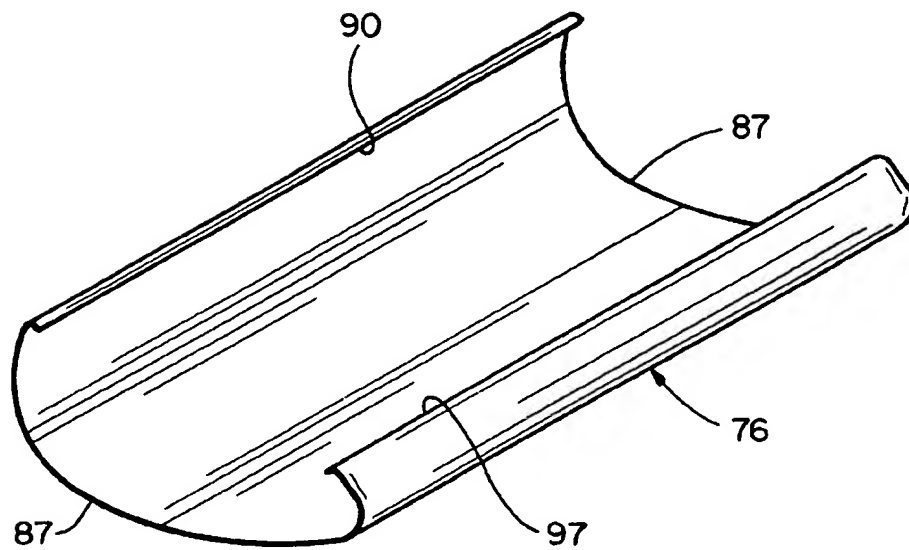
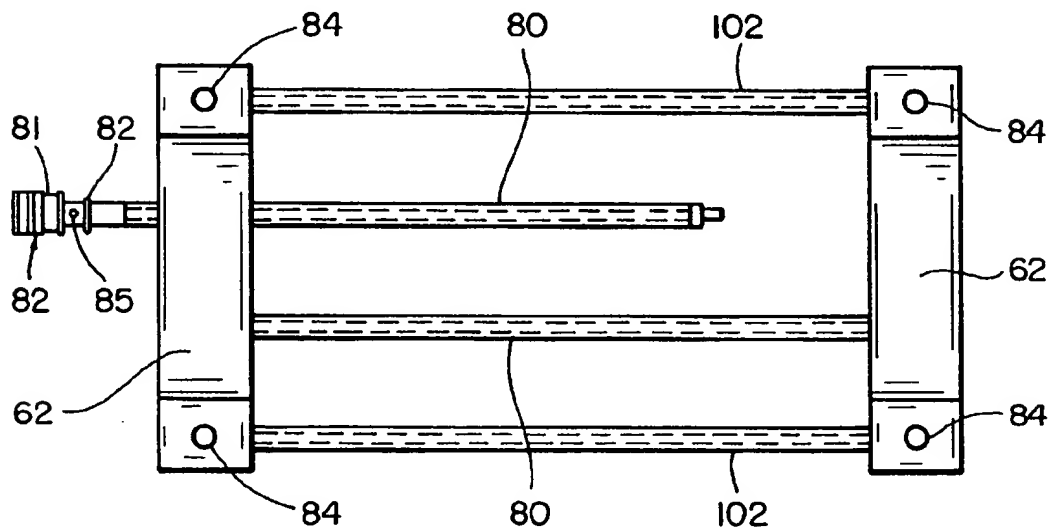


FIG-3

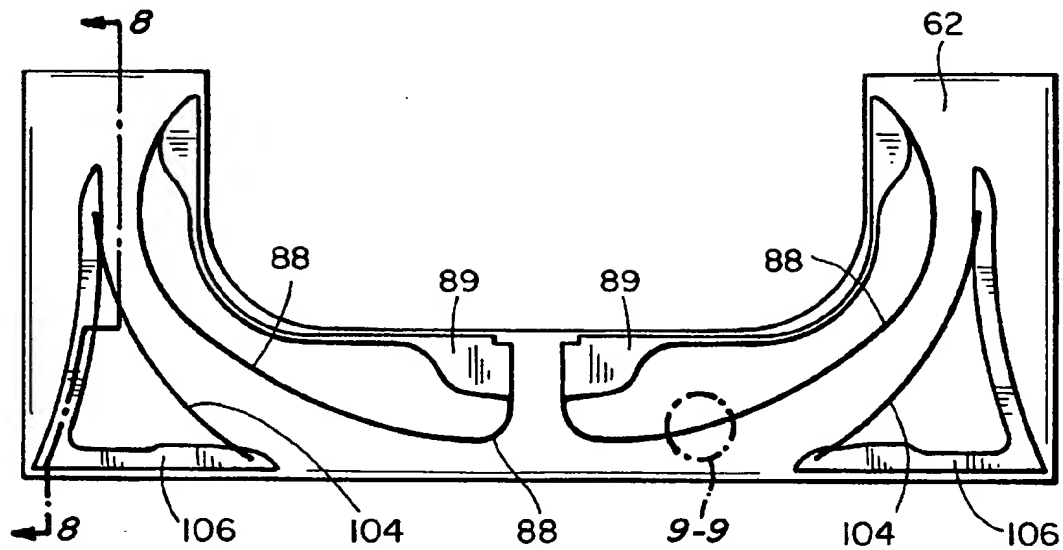
**FIG_4**



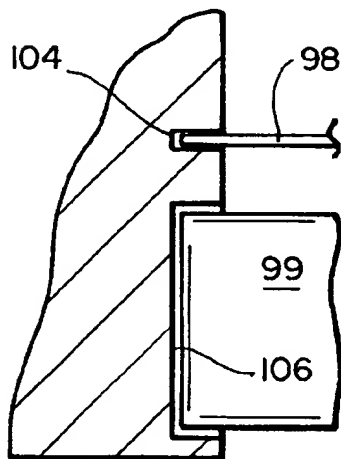
FIG_5



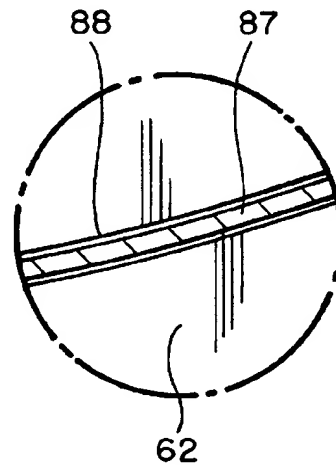
FIG_6



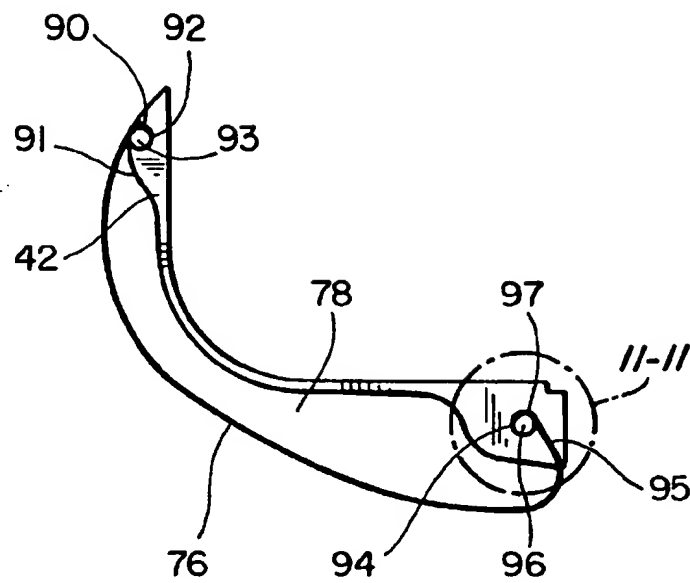
FIG_7



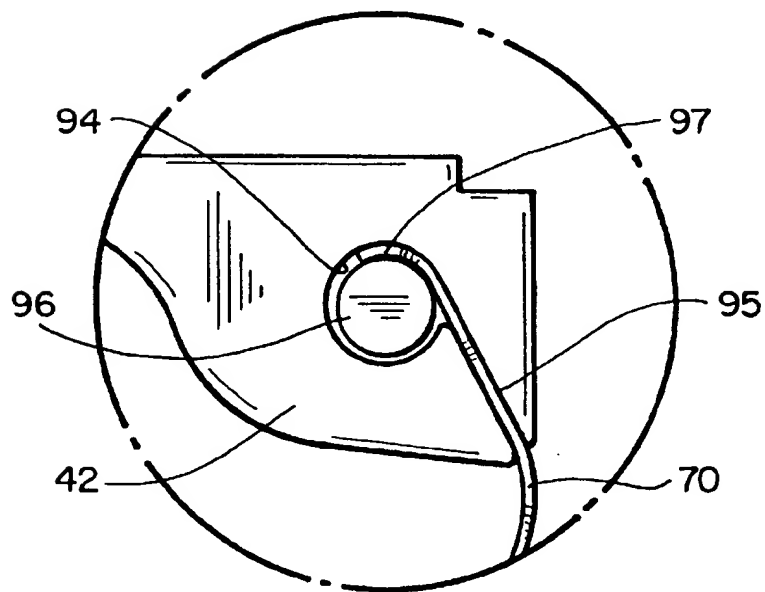
FIG_8



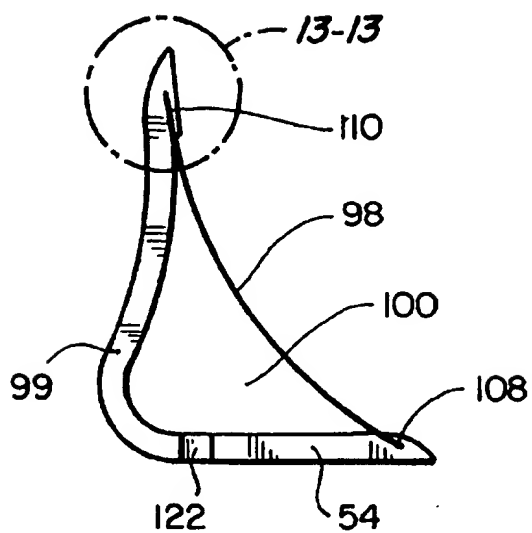
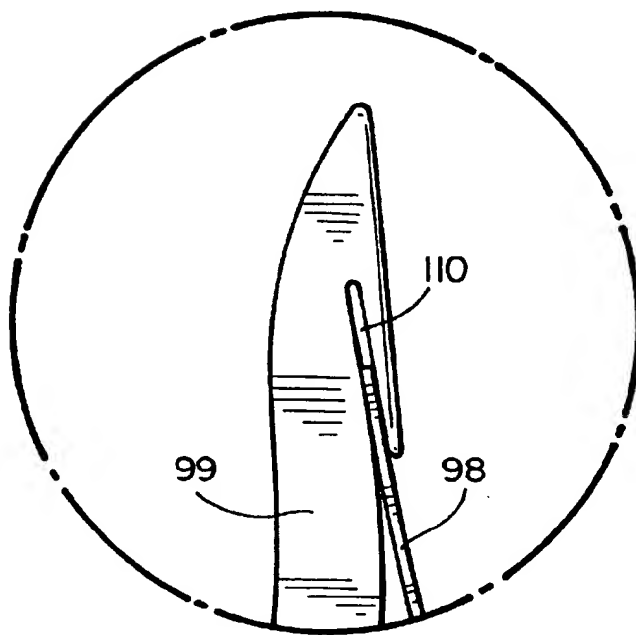
FIG_9

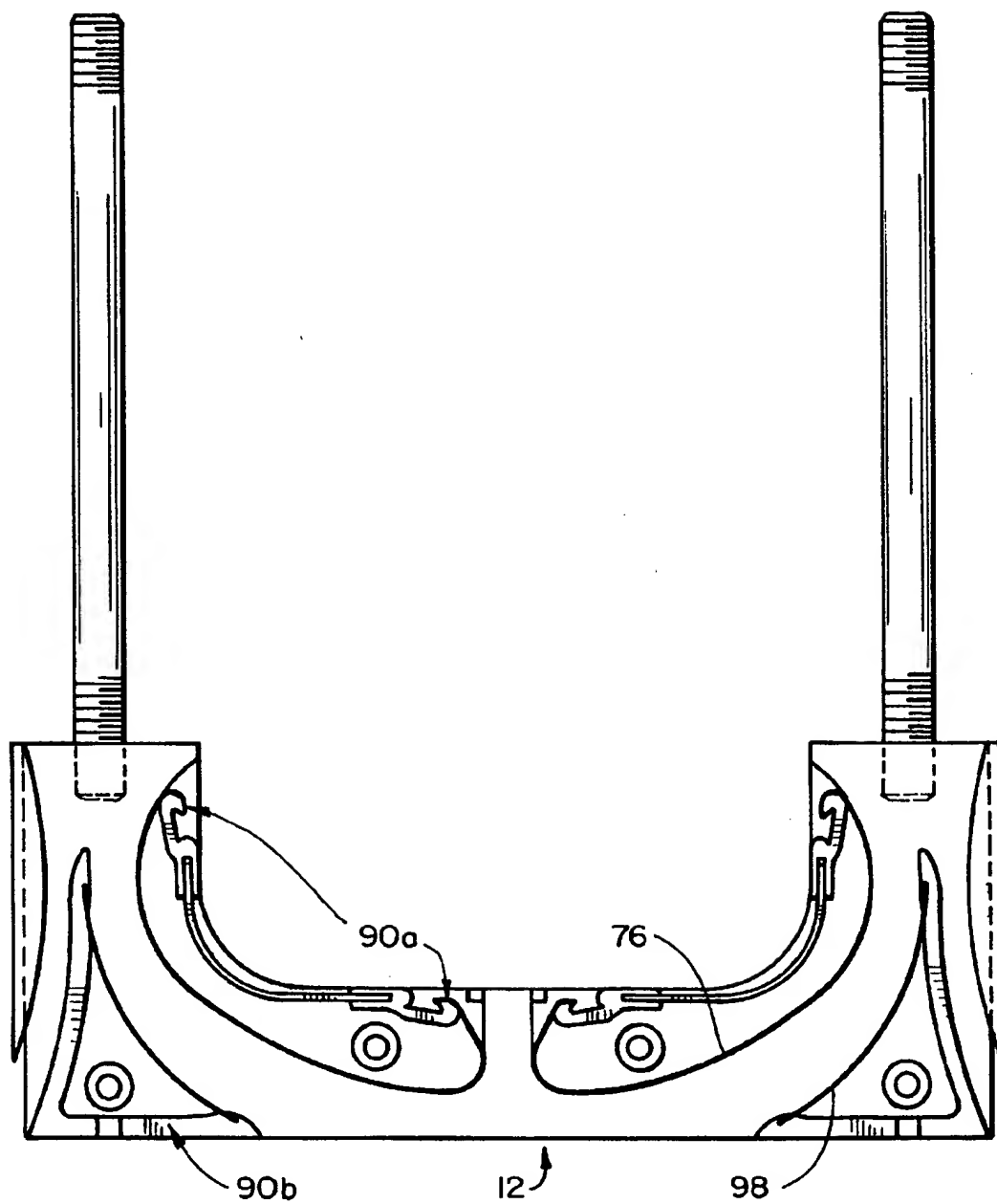


FIG_10



FIG_11

**FIG_12****FIG_13**

**FIG_14**

FREE FLOATING SHIELD

BRIEF DESCRIPTION OF THE INVENTION

The present invention relates in general to a protective shield for chemical vapor deposition systems and, more particularly, to a gas shield for reducing film deposition on the processing equipment.

BACKGROUND OF THE INVENTION

Chemical vapor deposition (CVD) systems are used to form a thin, uniform layer or film on a substrate such as a semiconductor silicon. During CVD processing, the substrate is exposed to one or more gaseous substances such as silane, phosphane, diborane, oxygen, ozone and the like, and chemical vapors such as TEOS (tetraethylorthosilicate), TMB (trimethylborate), TMPi (trimethylphosphate) and the like. The gases are injected into a clean, isolated reaction chamber and allowed to mix and interact with the other gases and/or the surface of the substrate to produce the desired film. The CVD systems typically employ injectors which deliver the gaseous substances directly to the surface of the substrate. An exhaust system removes waste products, such as unreacted gases and powders formed during the reaction, from the reaction chamber. Over time, films are deposited on the exposed surfaces of the chamber creating sources of particulate contamination which may become embedded in the film or degrade film uniformity. In many applications including semiconductor processing, film characteristics such as purity and thickness uniformity must meet high quality standards. To preserve film quality and prevent unacceptable defect levels, the reaction chamber must be cleaned to remove the deposited films.

The injection ports are typically positioned less than one inch from the surface of the substrate. With this limited clearance between the injector and the substrate surface, the surfaces of the injector and chamber walls will become coated with the material produced during the reactions. To reduce the amount of build-up in this area, some CVD systems include shields which are positioned in front of the injectors and exhaust port. The shields include a perforated screen welded to a support body. Supply tubes deliver an inert gas such as nitrogen to the volume between the support body and the screen. The nitrogen exits the shield through the perforated screen to slow the rate at which materials accumulate on the shield during processing.

The desired reactions for chemical vapor deposition typically occur at elevated temperatures, for example 300° C. to 600° C., with the substrate and chamber being heated to the appropriate temperature for a selected process. The high temperatures in the reaction chamber create thermal stresses in the perforated screen which may cause the screen to buckle after a period of time. The thermal deformation of the perforated screen disrupts the uniform flow of nitrogen through the screen, leaving portions of the screen unprotected against the accumulation of deposition materials. The ability of the screen to deliver nitrogen to the reaction chamber is further reduced as the screen becomes coated with deposition materials, requiring removal and cleaning or replacement of the shield. Since the screen essentially defines an upper "wall" of the reaction chamber, the deformed screen also interferes with the uniformity and distribution of the process reactant chemistries within the reaction chamber. The delays created by removal of the shield for cleaning or the replacement of a damaged shield are time consuming and expensive. A shield in which thermal deformation of the screen is minimized or climi-

nated is desirable. A shield which provides a uniform supply of the inert gas to the reaction chamber is also desirable. A shield in which a damaged screen surface can be quickly and inexpensively replaced is similarly desirable.

For atmospheric pressure CVD (APCVD) processing, the substrates are transported during processing by a conveyor which carries the substrates through one or more reaction chambers. The reaction chamber is not an enclosed chamber, but is merely the area in front of the injector between a series of curtains which use an inert gas such as nitrogen to isolate the reaction chamber from the rest of the process path. The exhaust vents on either side of the injector are used to extract unused gases and reaction by-products from the reaction chamber. If the exhaust is extracted at a rate slower than the rate at which the gases are introduced to the reaction chamber, some of the reactants may escape from the reaction chamber. Thus, with prior art systems the flow rate of the exhaust is typically greater than the rate at which gases are injected into the chamber, with excess inert gas being drawn into the reaction chamber from the area between the reaction chambers to provide a buffer zone blocking the escape of reactant gases. However, the gas drawn into the chamber from the adjacent buffer zones is not uniformly metered across the width of the reaction chamber. Thus, a non-uniform gas-to-gas boundary is created along the width of the reaction chamber. A shield which effectively prevented the escape of reactant gases from the reaction chamber without interfering with the reaction chemistries is desirable. As gases are pulled into the exhaust vent from the area below the injector on one side of the vent and the buffer zone between the reaction chambers on the other side of the vent, a large volume of reactant gas recirculation is created between the opposing flow streams. A shield which efficiently exhausts reactant gases from the chamber and minimizes the amount of gas recirculation within the reaction chamber is desirable.

OBJECTS AND SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide a shield assembly for protecting the exposed surfaces of a gas injector, chamber wall, or exhaust vent used in CVD processing.

It is a further object of the present invention to provide a shield assembly which uniformly delivers an inert gas to surfaces of the shield assembly during extended use of the shield assembly, and allows use of a smooth undistorted surface shape.

It is another object of the present invention to provide a shield assembly which will withstand the high temperatures necessary for the chemical reactions occurring within the chamber, without gas leakage or deformation of the shield assembly or surface delivering protective gas flow.

It is yet another object of the present invention to provide a shield assembly with removable and replaceable screens.

It is another object of the present invention to provide a shield assembly which provides separate dual exhaust paths for reactant gases and by-products versus ambient gas drawn into the chamber.

It is still another object of the present invention to provide a shield assembly which creates an inert gas buffer zone preventing the escape of reactant gases from the chamber.

It is another object of the present invention to provide a shield assembly which can supply excess inert gas to flow out of the chamber instead of requiring adjacent ambient gas to be drawn into the chamber in order to prevent the escape of reactant gases from the chamber in an open APCVD system.

It is an additional object of the present invention to provide a shield assembly which minimizes recirculation of the reactant gases within the chamber while protecting the exhaust vent path surfaces.

Another object of the present invention is to provide a shield assembly allowing a new muffle design having APCVD process modules or chambers isolated by buffer modules which extract excess inert gas from the chambers rather than supply excess gas drawn into the process chambers.

A more general object of the present invention is to provide a shield assembly which has a prolonged useful life, reducing the maintenance costs and maximizing the operational time of the CVD system, and which may be economically and efficiently manufactured and maintained.

In summary, this invention provides a durable protective shield for protecting the CVD equipment from excess film deposition and safely isolating the reaction chamber from the remainder of the process path. The shield includes a frame assembly including a pair of spaced end walls and a pair of side walls extending between and mounted to the end walls. A plurality of shield bodies are carried by the frame assembly, including injector shield bodies positioned for protection against injected reagents from the injector and shunt shield bodies spaced from the injector shield bodies for protection against exhausted reagents. Each of the shield bodies include a base, a perforated sheet carried by the base, a plenum between the base and the perforated sheet, and a gas delivery device for delivering an inert gas to the plenum at a flow rate such that the gas diffuses through the perforated sheet. In one aspect of the invention, the shield bodies are captured within the frame assembly such that the shield bodies can freely expand and contract relative to the frame assembly under varying temperature conditions. In another aspect of the invention, the perforated sheets are captured by the shield body base and end walls such that the sheets can freely expand and contract relative to the base and end walls under varying temperature conditions, maintaining the precise geometry requirements for CVD films. In another aspect of the invention, the shunt shield bodies each include an outlet port for supplying inert gas to areas below the shield to form buffer zones of inert gas on either side of the deposition zone within the processing chamber.

The invention also includes an atmospheric pressure chemical vapor deposition system which includes a plurality of processing chambers each having an injector therein for injecting reagents into the processing chamber and exhaust vents positioned on opposite sides of the injector. A conveyor transports substrates through the processing chambers along a process path. A plurality of buffer chambers isolate the processing chambers from the rest of the process path. A muffle encloses the processing chambers, the buffer chambers and the process path of the conveyor, and includes a by-pass ducts for venting the buffer chambers of muffle. A protective shield is mounted in the processing chambers for protecting the surface of the injector and the inlets of the exhaust ports. The protective shield includes injector shield bodies positioned adjacent the injector and shunt shield bodies spaced from the injector shield bodies. The shield includes an inlet port between the injector shield bodies and an outlet port between the shunt shield bodies for the flow of reagents through the protective shield. The shunt shield bodies each include a plenum filled with an inert gas and a bottom outlet port coupled to the plenum for delivering a supply of inert gas below the protective shield to form buffer barriers on opposite sides of the injection ports. This APCVD system configuration is novel in that the new

protective shield can supply excess inert gas from within the processing chambers such that all flow within the buffer chambers exits the muffle through by-pass ducts instead of being drawn into the chamber process exhaust vents.

Additional objects and features of the invention will be more readily apparent from the following detailed description and appended claims when taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an existing prior art (APCVD) processing system which can incorporate a new protective shield in accordance with the present invention.

FIG. 2 is a schematic view of a processing module or chamber of the CVD system of FIG. 1, illustrating an existing prior art type of gas shield.

FIG. 3 is a schematic view, partially broken away, of a protective shield in accordance with the present invention, shown installed in a processing module.

FIG. 4 is pictorial view of the shield assembly of FIG. 3.

FIG. 5 is a pictorial view of the preformed perforated screen spanning the surface between the injector outlet port and inner exhaust vent of the shield assembly of FIG. 3.

FIG. 6 is a top plan view of the end walls and internal metering tubes of the shield assembly of FIG. 3.

FIG. 7 is a front plan view of an end wall of the shield assembly of FIG. 3.

FIG. 8 is a cross-sectional view taken substantially along line 8—8 of FIG. 7.

FIG. 9 is an enlarged view taken substantially of area within circle 9—9 of FIG. 7.

FIG. 10 is an end view of an injector section gas delivery assembly of the shield assembly of FIG. 3.

FIG. 11 is an enlarged view taken substantially of area within circle 11—11 in FIG. 10.

FIG. 12 is an end view of the shunt section gas delivery assembly of the shield assembly of FIG. 3.

FIG. 13 is an enlarged view taken substantially of area within circle 13—13 in FIG. 12.

FIG. 14 is a cross-sectional view of a shield assembly in accordance with another embodiment of the invention.

FIG. 15 is a schematic view of a new CVD system process muffle enabled to exhaust excess chamber gas out buffer modules while ensuring safe containment of process gases through use of the new shield.

DETAILED DESCRIPTION OF THE INVENTION

Reference will now be made in detail to the preferred embodiment of the invention, which is illustrated in the accompanying figures. Turning now to the drawings, wherein like components are designated by like reference numerals throughout the various figures, attention is directed to FIGS. 1 and 2.

FIG. 1 schematically illustrates a section of an existing prior art CVD processing system 10 with which the protective shield assembly of this invention is used. As is known in the art, atmospheric pressure CVD systems typically include one or more processing modules or chambers 11 positioned along the process path. The components of the processing module 11 are shown in FIG. 2. Each processing module 11 includes an injector 14 for injecting chemical reagents and other gaseous substances into a reaction cham-

ber or process area, generally designated 16, directly below the injector 14. In the illustrated example, the CVD system 10 includes four processing modules 11 as shown in FIG. 1, although it is to be understood that the number of processing modules 11 employed depends upon the constraints of a particular process. Conduits 18 deliver the gaseous substances to the injectors 14, which transport the gases through separate flow paths to one of the injection ports 20. Although not shown, each port 20 extends lengthwise along the longitudinal axis of the injector 14 to deliver the gaseous substance in a sheet-like flow to the reaction chamber 16. The substrate 22 is transported along the process path by a conveyor 24.

The entire process path is enclosed within a muffle 26 which provides a clean, contaminant free environment for the transport and processing of the substrate. As shown in FIG. 1, the processing modules 11 are separated by buffer modules 27 which isolate the processing modules 11 from the rest of the processing path. As shown in FIG. 2, the buffer modules 27 include a plurality of curtains 28 hanging from a plenum body 30 which is used to deliver an inert gas such as nitrogen between the curtains 28. Deposition waste products including unreacted gas are expelled from the reaction chambers 16 through exhaust vents 32 which are coupled to a suitable exhaust system (not shown). The chamber deposition area 16 and substrate 22 are retained at the desired reaction temperature by heating elements 34.

As the substrate is moved through each reaction chamber 11, the injected substances react with each other and/or with the upper surface of the substrate 22 to form a thin, uniform layer or film. The actual reagents used in the CVD process depend in part upon the type and quality of film desired. In one application of the processing system 10, the inner port 20 is coupled via injector 14 and one conduit 18 to a silicon source reactant such as TEOS, silane or disilane with nitrogen, and if desired a dopant source reactant such as TMPi, TMB, phosphine and/or diborane. The reagent is typically supplied with an inert carrier gas such as nitrogen. Oxygen or a combination of oxygen and ozone and nitrogen is delivered through another conduit 18 and the injector 14 to the outer ports 20. A stream of pure nitrogen travels through another conduit 18 to the intermediate separator ports 20 to separate the silicon, boron, and phosphorus source reactant from the oxidizing species until the gases approach the wafer surface.

One application of the shield 12 of this invention is described herein. Specifically, the shield 12 is shown protecting the front face of the injector 14 and the inlets of the exhaust vents 32. However, it is to be understood that the shield 12 may also be used in other applications such as protection of the chamber walls of process modules, or protection of the exhaust vent path including outlets. In addition, shield 12 can be applied to CVD systems operating at various pressures, not only at atmospheric pressure, such as for sub-atmospheric (SACVD) or low pressure (LPCVD) or high pressure systems. Shield 12 can also be applied to various film depositions of different composition, not only silicon oxide (SiO_2) or borophosphosilicate glass (BPSG) systems. The subject matter of this invention is not to be limited to any specific application.

Turning to FIGS. 3 and 4, the shield assembly 12 of this invention is positioned in front of the injector 14 and the inlets of the exhaust passageways 32 where it protects these surfaces against film deposition and the accumulation of potential contaminants. Unlike prior art shields, the shield assembly 12 of this invention also more precisely defines the boundaries of the reaction chamber deposition area 16. As

discussed in more detail below, the shield 12 also prevents migration of the reagents outside the shunt sections of the shield 12, confining the reaction chamber deposition zone 16 to a precisely defined area. By controlling the size of the deposition area, the shield 12 of this invention provides greater control over the reaction chemistries and flow occurring within the chamber, thereby improving the quality and uniformity of the film deposited on the substrate.

The shield 12 has a modular construction and generally includes a number of separate shield bodies 40. Two of the shield bodies 40a and 40b cooperate to define the back wall 42 of the shield body 12 which is positioned against the front face of the injector 14 to wrap around the outer edges of the injector 14. This configuration ensures the front face of the injector 14 and the inlet edges 50 of the exhaust vents 32 will be substantially isolated from reaction by-products and unused reagents. The shield bodies 40a and 40b are spaced apart to define an inlet port 46 of the shield for the flow of the reagents injected by injector 14 through the shield. The size, shape and configuration of the inlet port 46 is dependent upon the configuration of the injection ports 20 of the specific injector 14 employed in the processing system 10. In this embodiment, the inlet port 46 has a narrow, elongate configuration and is sized so that the edge of the port 46 is positioned just outside of the outermost injection ports 20 to provide maximum protection for the front face of the injector 14. However, it is to be understood that the configuration of the inlet port 46 is subject to considerable variation within the scope of this invention. For example, in other modifications of the invention the shield bodies 40a and 40b may be combined into a single assembly and the inlet port 46 defined by an opening formed through the unitary assembly.

Shield bodies 40c and 40d are positioned below, and slightly outwardly of, the shield bodies 40a and 40b, with the inside edges 48 of the shield bodies 40c and 40d cooperating to define the beginning of the inner exhaust paths 116 leading to the exhaust vent inlets 50 of the exhaust vents 32 to remove process gases from the deposition zone 16. The shield bodies 40c and 40d are spaced apart, forming an outlet port 58 of the shield assembly 12 therebetween. The outlet port 58 is aligned with the inlet port 46, and is considerably larger than the inlet port 46. Since the shield 12 of this invention provides the boundaries of the reaction chamber deposition zone 16, the width of the outlet port 58 substantially defines the deposition area. In the illustrated embodiment, the outlet port 58 has a width of about 2.5 inches compared to the inlet port width of 0.25 inches. However, it is to be understood that the size and configuration of the outlet port 58 may be tailored to the constraints of a particular application.

The shield bodies 40 mate with end walls 62 to form the enclosed volume through which protective gas is introduced. The end walls 62 also have a U-shaped configuration to wrap around the front of the injector 14. Side walls 64 are mounted to the end walls 62 by bolts 63 or other suitable fasteners, thereby securing the various components of the shield 12 together. In the preferred embodiment, the shield bodies 40 are not mounted directly to the end walls 62 but allowed to expand and contract under varying temperature conditions as is described below in relation to FIGS. 7 and 8. The end walls 62 include outward projecting dowels 65 which facilitate assembly of the shield 12 by providing the correct alignment and spacing of said end walls when the side walls 64 are attached. Using bolts or other similar fasteners to secure the side walls 64 to the end walls 62, with the shield bodies 40 captured within this framework, allows

the shield bodies to be easily assembled and taken apart, providing a modular shield body 12 which may be conveniently cleaned and maintained as is described in more detail below. However, in other forms of the invention, means which do not permit quick dismantling of the shield 12 may be used to secure the shield together.

The side walls 64 are spaced outwardly of the shield bodies 40a and 40b to define exhaust ports 50 for delivering exhaust directly to the exhaust vents 32. The upward-extending portion of the shield bodies 40c and 40d is spaced from the interior of the side walls 64, thereby dividing the gas flow path into exhaust ports 50 into two sections on each side, the purpose of which is described in more detail below. The side openings 66, which allow substrates to be transported through the process modules 11, also provide for the passage of gases from the buffer modules 27 outside the process modules 11 through the exhaust paths 68 formed between the inside edges of the side walls 64 and the exterior of the shield bodies 40c and 40d to the exhaust port 50. Instead of using the gap between the side walls 64 and the upward extending portions of the shield bodies 40c and 40d to form the side exhaust paths 68, it is to be understood that the side exhaust port may be provided by an opening in the side walls 64. In another embodiment of the invention, inert gas introduced through the shield bodies 40c and 40d may flow up the outer exhaust paths 68 and out into the buffer zones 27 through openings 66.

The exposed surfaces of the shield bodies 40 are protected from the chemical reagents by barriers of inert gas such as nitrogen, argon, helium or other suitable gases. The nitrogen minimizes film deposition by blocking the surfaces of the shield bodies 40 from the chemical reagent stream. Since shield bodies 40a and 40b are substantially identical, although reversed relative to one another, only shield body 40a will be described in detail with the description applying equally to shield body 40b. The shield body 40a includes a perforated sheet or screen 76 which is bent or pre-formed to the desired shape, shown in FIG. 5, such that the sheet 76 stands away from the base 42 of the shield body 40a to form a plenum 78. The perforated sheet preferably has a thickness in the range of 0.005 to 0.012 inches, for example 0.008 inches. Suitable materials for the perforated sheet include stainless steel, inconel, or other similar alloys. The porosity of the screen is on the order of 10%–30%.

A gas supply device is used to fill the plenum 78 with an inert gas such as nitrogen at a flow rate such that the nitrogen permeates the perforated sheet 76 and forms a nitrogen cloud in front of the sheet 76. In the illustrated embodiment, one or more conduits or metering tubes 80 are positioned in the plenum 78 and coupled through the end walls 62 to an exterior source of inert gas (not shown) for delivering the gas to the plenum. The wall of the metering tube 80 is porous, allowing the gas to diffuse uniformly through the tube wall in all directions. Thus, extraction of the gas from the metering tube is not limited to discrete holes formed in the conduit wall as in prior art systems. With such prior art systems, the discrete holes drilled in the solid tube cause the gas to exit each hole at a high velocity, maintaining a high degree of momentum from the thin metal surface and creating localized jets of gas within the plenum. These localized jets result in a non-uniform distribution of inert gas in the plenum and along the front of the screen, adversely affecting the protection afforded against more rapid deposition on the screen and the uniformity of the reagents within the chamber and the uniformity of the deposited film. With the metering tube 80 of the present invention, the gas diffusion occurs evenly along the entire length and circum-

ference of the tube, filling the entire plenum with the gas at a uniform rate. Thus, the conduit 80 provides a low-velocity, uniform supply of gas free of localized effects. Materials for conduit 80 which exhibit the desired porosity include nickel, stainless steel, or silicon carbide. While the metering tubes 80 are preferred, it is to be understood that the conduits 80 may be replaced with the prior art conduits having a solid wall formed with a series of holes for injecting the inert gas into the plenum.

To achieve a uniform distribution of gas within the plenum, the metering tube 80 or a number of conduits in combination preferably extend substantially along the length of the plenum 78. As shown particularly in FIG. 3, the metering tube 80 is located in the vicinity of the inlet port 46 to provide a substantial nitrogen concentration in the deposition zone. The nitrogen or other inert gas is supplied to metering tube 80 at a flow rate which ensures the plenum will be continuously filled with sufficient gas to provide a satisfactory gas barrier across the entire surface of the perforated sheet 76. Typical flow rates of nitrogen gas used in shield bodies 40a and 40b for the APCVD process modules described herein are approximately 5 to 15 standard liters per minute.

In the preferred embodiment, the shield 12 has a modular design to be easily and conveniently cleaned and maintained. As shown in FIG. 6, the metering tube 80 is inserted through an opening formed in the end wall 62 and secured in place via a mounting member 81 provided at the end of the conduit. C-ring seals 82 or other suitable sealing means provide a seal between the metering tube 80 and the end wall 62. Gas is delivered to the end wall 62 via gas supply tubes 83 (FIG. 4) and fittings 84. The gas flows through internal passages formed in the end wall (not shown) and enters the metering tube 80 via an opening 85 in the tube. In this embodiment, the metering tube 80 of each shield body 40a and 40b is inserted through a different one of the end walls 62. However, in other modifications of the invention, the metering tubes 80 for both shield bodies 40a and 40b may be inserted through the same end wall. Inserting the metering tubes through the end walls allows the metering tubes 80 to be easily removed without detaching one or both of the end walls 62 or removing the screens 76. While the ability to remove the conduit 80 through the end plate 62 is advantageous, it is to be understood that other embodiments of the invention may include conduits which are entirely contained within the plenum 78 or attached to the inside of an end wall, requiring removal of an end plate 62 to remove the conduit.

CVD processing typically occurs at elevated temperatures, often as hot as 600° C. With prior art shields, the screen is exposed to the hot chamber while the shield backplate is situated behind a plenum filled with a continuous stream of nitrogen. Thus, the back plate is at a lower temperature than the screen. The smaller thickness, lower mass, and higher temperature of the screen causes the screen to expand faster and to a greater extent relative to the backplate. Since the screen is welded directly to the backplate, this thermal expansion causes the screen to warp, bend or buckle. Repeated heating of the shield may cause the screen to crack. Prior art shields have used embossed indentations formed in the screen or other means to reduce this buckling effect. However, these measures have not completely overcome the buckling problem. Moreover, the deformation of the screen and the embossed indentations distort the geometry of the reaction chamber, interfering with the uniform distribution of reagents within the chamber deposition zone 16. With the shield 12 of this invention,

buckling of the perforated screen is substantially eliminated as it is free floating rather than constrained at its edges.

In the preferred embodiment of the invention, the shield body 40a is not affixed or welded to the end walls 62, and the perforated sheet 76 is not affixed or welded to the shield base 42 or end walls 62. Instead, the shield body 40a and the perforated sheet 76 are held in place in a manner which permits movement of the shield body 40a and sheet 76 relative to the framework of the end and side walls 62 and 64 as the shield body 40a and sheet 76 expand and contract under varying temperature conditions without creating internal compressive stresses which could lead to buckling, warping and the like. The interior of at least one and preferably both of the end walls 62 are shaped to hold the ends of the perforated sheet 76 and the base 42 of the shield body. As shown in FIGS. 7 and 9, the end wall 62 includes a channel 88 formed in the end wall 62 which corresponds to the shape of the pre-bent perforated sheet 76. The ends 87 of the perforated sheet are seated in a channel 88, with the walls of the channel 88 holding the sheet ends in place. The end wall 62 also includes a recessed area 89 which conforms to the shape of the base 42 of the shield body 40a. The shield body 40a is seated in this recessed area to couple the shield body 40a to the end walls 62. The walls of the channel 88 and the recessed area 89 also substantially seal the ends of the sheet, preventing the flow of gas around the end of the perforated sheet.

The channel 88 and recessed area 89 have a depth such that, at temperatures near room temperature, there is a significant gap between the ends of the sheet 76 and base 42 of the shield body 40a to the closed end of the channel 88 and recessed area 89. At the elevated operating temperatures, which are typically greater than 400°, the perforated sheet 76 and base 42 can expand, causing the ends of the sheet 76 to substantially fill the channel 88. The channels 88 and recessed areas 89, which are formed in both end walls 62, accommodate expansion of the perforated sheet, minimizing or even eliminating buckling or warping of the perforated sheet. In the present embodiment, in which the perforated sheet 76 is formed of stainless steel and has a thickness of about 0.008 inch and an insertion length of about 0.150 inch into the channel 88, the channel 88 has a depth in the range of 0.200 inch and a breadth in the range of 0.0085 to 0.010 inch. The recessed area 89 also has a depth in the range of 0.200 inch to accommodate a similar insertion depth of 0.150 inch of the base 42, and the tolerance in the range of 0.001 to 0.005 inch in breadth greater than the shape of the base 42.

The side edges 90 and 97 of the perforated sheet 76 are held by the shield body 40a in a manner which permits movement of the sheet 76 relative to the base 42 of the shield body. As shown in FIGS. 10, the base 42 of the shield body 40a includes a curved support surface 91 having a longitudinally extending bore 92 formed therein. The side edge 90 of the perforated screen 76 is slipped into the bore 92 and the locking pin 93 slipped into the space between side screen edge 90 and the wall of the groove 92. While the pin 93 holds the edge 90 of the screen 76 in the groove, the pin is not affixed to either the sheet 76 or the base 42. As the screen 76 expands under elevated temperature conditions, the side edge of the screen 90 is allowed to travel in a clockwise direction around the pin 93 such that the sheet 76 may expand without creating the internal forces which will eventually damage or distort the sheet. As shown in FIGS. 10 and 11, the base 42 of the shield body 40a also includes a longitudinally extending bore 94 formed through the base 42. A slit 95 extends outwardly from the bore 94. The side

edge 97 of the perforated sheet 76 is inserted through the slit 95 and into the bore 94, a locking pin 96 inserted into the bore 94 secures the sheet edge in place, while permitting the sheet edge to expand around the locking pin 96 as described above.

The shield bodies 40c and 40d are similar to the shield bodies 40a and 40b. Only shield body 40c is described in detail since the shield bodies 40c and 40d are identical, although reversed relative to one another. This description applies equally to the shield body 40d. The shield body 40c includes a perforated sheet or screen 98 which is spaced from the base 99 of the shield body 40c, forming a plenum 100 between the perforated sheet 98 and the base 99. A gas supply device, such as one or more metering tubes 102, fills the plenum with an inert gas such as nitrogen. The metering tube 102 is substantially identical to the metering tube 80, described above. In this embodiment, the metering tube 102 of each shield body 40c and 40d extends through a different one of the end walls 62. However, if desired the metering tubes 102 of both bodies 40c and 40d may be mounted to the same end wall 62. The metering tube 102 fills the plenum 100 with the gas, and the gas passes through the sheet 98 and forms a gaseous cloud in front of the screen 98 to inhibit film deposition on the screen.

As with shield body 40a, the shield body 40c is captured by the end walls 62 and the perforated sheet 98 is captured by the shield base 99 and end walls 62 such that the base 99 and perforated sheet 98 are movable relative to the end walls 62 and each other during expansion and contraction of the sheet under varying temperature conditions. The end walls 62 include a channel 104 into which the ends of the perforated sheet 98 are seated (FIGS. 7-8). The end wall 62 is also formed with a recessed area 106 shaped to receive the ends of the base 99 of the shield body 40c. The walls of the channel 104 and recessed area 106 hold the shield body 40c in place and prevent the leakage of gas from the ends of the plenum 100. A gap exists between the edges of the perforated sheet 98 and base 99 to the bottom of the channel 104 and recessed area 106 to permit expansion of the perforated sheet 98 and the base 99 under varying temperature conditions. As discussed above in relative to the shield body 40a, the perforated sheet 98 and base 99 can expand as temperatures increase causing the ends of the sheet to move deeper into the channels 104 and the ends of the base 99 to move deeper into the recessed area 106. Thus, the channel 104 and recessed area 106 of the end walls 62 hold the shield body 40c in place while permitting expansion and contraction of the shield body 40c and screen 98 under varying temperature conditions.

The side edges of the perforated sheet 98 are also retained by the base 99 of the shield body 40c in a manner which permits movement of the screen 98 relative to the base 99 as the screen expands and contracts. As shown particularly in FIGS. 12 and 13, the base 99 includes a first retainer 108 and a second retainer 110 for holding the side edges of the perforated sheet 98. In this embodiment, the retaining members 108 and 110 are provided by longitudinally extending slots formed in the base 99. The side edges of the perforated screen 98 are seated in the slots 108 and 110, which hold the edges in place while permitting expansion and contraction of the screen 98 under varying temperature conditions. In this embodiment, the slots 108, 110 each have a depth of about 0.10 inch and a width of about 0.010 inch.

With the channels and recessed areas formed in the end walls 62 and the configuration of the base 42 of the shield bodies 40a, 40b and the base 99 of the shield bodies 40c, 40d, the perforated sheets 76 and 98 may be easily slipped

into said bases and said shield bodies inserted into said end walls. The shield assembly 12 is easily completed by attaching the side plates 64 to the end wall 62 with as few as four bolts 63, and inserting the four metering tubes 80 and 102, each with a single fitting 81. Even with the nitrogen barriers, some film may be deposited on the surfaces of the perforated sheets 76 and 98 after processing for extended periods of time. When the accumulated film begins to interfere with the operation of the shield 12, the shield 12 may be easily dismantled to remove the shield bodies 40 for cleaning or replacement of the coated screens. New or clean screens 76 and 98 or shield bodies 40 may be installed for continuous operation while the used screens or bodies 40 are cleaned, reducing the time during which the processing system 10 is idle or shut down. The shield bodies 40 and screens 76 and 98 may be reused at a later time after they have been cleaned. The porous metering tubes 80 and 102 may also be easily removed from a whole shield body 12, in case cleaning of the remaining parts as a unit is desired.

FIG. 14 shows an embodiment of a shield body 12 which includes a different type of retainer 90a for holding the perforated screen in place. The principle of operation is the same as the technique already described to attach screen 76 to base 42 (FIG. 10) in that two parts interlock, creating the geometry which acts to capture the screen without constraining the edge of the screen. The shape of retainer 90a is just different than the simple rods 93 and 96 used for shield body 40a.

Additionally, different shapes of the slots and screen edges than described to attach screen 98 to base 99 (FIG. 12) can be employed as well, as shown in FIG. 14 by slot 90b.

As is shown in FIG. 3, the passageways 116 provided between the shield bodies 40a and 40b and the shield bodies 40c and 40d deliver unused reagents and reaction by-products directly to the exhaust ports 50, ensuring the efficient removal of the process exhaust from the deposition zone 16. This is different from prior art shields, which do not direct the gases to the exhaust vents within a controlled path, but merely provide a layer of inert gas in front of the exposed surfaces of the injector and exhaust vent inlets. Nitrogen emitted through and covering the perforated sheets 76, 98 isolates the perforated sheets from the chemical reagent stream and inhibits deposition of film on the surface of the perforated sheets. A uniform supply of the inert gas is provided in front of each perforated screen since buckling, warping or other deformation of the screen is avoided by allowing the screens to move relative to the shield body and end plates under varying temperature conditions. Thus, the more uniform layers of inert gas improves the quality of the deposited film by reducing the accumulation of contaminants within the chamber and promoting uniform distribution of the reagents within the chamber.

With the shield 12 of this invention, the deposition area 16 is confined to the area of the substrate directly below the outlet port 58. As shown in FIGS. 3 and 12, the shield bodies 40c and 40d each create dual exhaust paths to the exhaust vent inlet 50 and also include a bottom outlet port 122 formed in the base 99 of the assembly. The bottom outlet port 122 causes a stream of inert gas to flow from the plenum 100 through the base 99 to the area below the shield adjacent to the outlet port 58. The substrate 22 or the conveyor 24 causes separation of the flow from the bottom outlet port 122 into a shunt containment flow, designated at 124, and a shunt outflow, designated at 126. The shunt containment flow 124 provides a buffer of inert gas below the shield bodies 40c and 40d, preventing the reagents or reaction by-products from leaving the deposition zone 16 by escaping beneath the

shield 12. The containment shunt flow 124 isolates the reaction chamber, allowing the width of the deposition zone to be precisely controlled and improving process performance.

The shunt outflow 126 flows around the shield bodies 40c, 40d and through the outer shunt exhaust path 68 to the exhaust port 50. Directing this stream of inert gas to the exhaust port 50 ensures the process exhaust via path 116 from the deposition area 16 will be carried directly to the exhaust vent 32 for extraction from the system 10 and also dilutes the chemical concentration and increases velocity to ease the removal of by-products. The shunt outflow 126 also provides a barrier between the buffer modules 27 and the reaction chamber deposition area 16, effectively isolating the reaction chamber from the conditions in the areas upstream and downstream of the process modules 11.

The shield 12 of this invention creates a buffer gas zone on opposite sides of the reaction chamber. The inert gas is delivered to the plenum 100 at a flow rate sufficiently high to maintain a constant flow stream for both the shunt containment flow 124 and the shunt outflow 126 as well as the protective flow through the screen 98, ensuring the desired buffer zone is created on either side of the deposition zone. With the shunt containment flow 124 and shunt outflow 126, the deposition zone boundary and the process gas flows can be precisely and uniformly controlled as all the gases are supplied and metered within the chamber, producing a higher quality film.

With prior art systems, an example of which is shown in FIGS. 1 and 2, the exhaust flow rate to vents 32 is greater than the rate at which gases are supplied within the chamber area of process modules 11 so that the inert gas supplied by plenums 30 or from the buffer modules 27 may be drawn into the reaction chamber to form a barrier preventing the escape of reagents into the curtain area. A problem with this system is that the buffer gas is typically provided and drawn into the chamber area through side openings 66 in a non-uniform distribution, resulting in a non-uniform distribution of reagents along the edges of the chamber which detracts from the uniformity of the film deposited on the substrate 22. The inflow of gas from the curtain area 27 and the flow of process exhaust from the injector 14 within the chamber to the exhaust vent 32 create a large stagnant pocket between the two flow streams where reagents and reaction by-products are recirculated. The recirculating gases interfere with the ability to precisely control the reaction chemistry within the complete deposition zone 16. These problems with the prior art processing systems are overcome by the shield of this invention.

With prior art shields, the recirculating flow is produced in the relatively large area between the exhaust inlet to vent 32 and the upper surface of the conveyor 24 or substrate 22. With the shield of this invention, the shunt containment flow 124 and the streamlined shape of the shield bodies 40c and 40d effectively minimizes the amount of recirculation of the reagents where the gas streams meet, ensuring the reagents are efficiently exhausted through exhaust vents 32. In the embodiment shown in FIG. 3, the shunt section shield bodies 40c and 40d are located to substantially physically block the large recirculation volume present in the prior art shield represented in FIG. 2.

With the shield 12 of this invention, the inert gas supplied by the shield bodies 40 ensures that the reagents and reaction-by-products will be safely retained within the deposition area 16. With the new shield 12 this containment can be accomplished where gas is introduced into the chamber

either at a lower or greater rate than the flow rate of the exhaust through vents 32. So inert gas can either be flowing into or out of the process module 11 through openings 66, whereas the prior art has to draw gas from buffer module 27 in through openings 66 to provide containment. The gas which is not accommodated by the exhaust vents 32 flows into the buffer modules 27 between the process modules 11 and is removed from the muffle via by-pass ducts 130 connecting the buffer modules 27 to a separately controlled exhaust vent, as shown in a new muffle design in FIG. 15. Since the reagents are safely contained within the reaction chamber and delivered directly to the exhaust ports 50 and vents 32, the gas which is vented through the by-pass valves is nitrogen. No reagent or by-products are carried to the by-pass vents 130. Utilizing the by-pass ducts 130 to extract excess inert gas from the process modules allows all the gas flow within the process chambers to be supplied and controlled by the geometry within the chambers, more effectively isolating the process results of deposition on wafers inside the chambers from any external disturbances or non-uniformity present as in an open APCVD system.

As is apparent from the forgoing, the present invention provides a shield 12 which may be used to achieve improved uniformity of reagents within the reaction chamber, greater control over the reaction chemistry residence time, and precise control over the geometry of the reaction chamber 16 and deposition zone, thereby enhancing the quality of the deposited film. The shield 12 can withstand changing temperature conditions without damaging or deforming parts of the shield which could reduce the effectiveness of the shield operation. The shield 12 is modular, and may be conveniently and quickly assembled and dismantled for maintenance or cleaning. The shield 12 includes metering tubes 80, 102 which deliver the inert gas to the plenum in a more uniform distribution, improving the uniformity of the reagents within the deposition zone 16. The shield is used to form a barrier or buffer zone on opposite sides of the reaction chamber, preventing reagents from escaping from the chamber and allowing a uniform distribution of buffer gas to be provided within the muffle 26. It is to be understood that this invention is not limited to the shield 12 of the illustrated embodiment which includes each of the features described herein. Instead, it is to be understood that shields incorporating only some of the features described herein is within the scope of this invention.

The foregoing descriptions of specific embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, to thereby enable others skilled in the art to best use the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto and their equivalents.

What is claimed is:

1. A protective shield for chemical vapor deposition systems comprising:

a frame assembly including a pair of spaced end walls and a pair of side walls extending between and mounted to said end walls; and

a plurality of shield bodies carried by said frame assembly, each of said shield bodies including a base, a perforated sheet carried by said base, a plenum

partially defined by said base and said perforated sheet, and a gas delivery device for delivering an inert gas to said plenum at a flow rate such that the gas diffuses through said perforated sheet.

2. The protective shield of claim 1 in which a pair of said shield bodies are positioned to define a first surface of said protective shield which is positionable proximate an injector body, said shield bodies being spaced apart to define an inlet port therebetween for the flow of reagents through said protective shield.

3. The protective shield of claim 2 in which a second pair of said shield bodies are positioned to define a second surface of said protective shield opposite said first surface, said second pair of said shield bodies being spaced apart to define an outlet port therebetween for the flow of reagents through said protective shield.

4. The protective shield of claim 3 in which said second pair of shield bodies include a bottom outlet port coupled to said plenums thereof for the flow of the inert gas through said shield bodies to form an inert gas barrier zone below said second surface on opposite sides of said outlet port.

5. The protective shield of claim 1 in which at least one of said shield bodies is spaced from one of said side walls to define an exhaust port therebetween.

6. The protective shield of claim 5 in which said shield extends between and is spaced from said one of said side walls and said at least one of said shield bodies to define a first exhaust passageway between said at least one of said shield bodies and said another of said shield bodies and a second passageway between said another of said shield bodies and said one of said side wall.

7. The protective shield of claim 1 in which said shield bodies each have spaced ends and said end walls are shaped to mate with the ends of said shield bodies to hold said shield bodies in said frame assembly.

8. The protective shield of claim 7 in which said end walls have slots formed therein shaped to make with the ends of said shield bodies and the ends of said shield bodies are seated in said slots.

9. The protective shield of claim 8 in which the ends of said shield bodies are movable within said slots as said shield bodies expand and contract under varying temperature conditions.

10. The protective shield of claim 1 in which said perforated sheet is held by said base such that said perforated sheet is movable relative to said base during expansion and contraction of said perforated sheet under varying temperature conditions.

11. The protective shield of claim 10 in which said base has a slot formed therein and said perforated sheet is seated in said slot and movable within said slot during expansion and contraction of said perforated sheet under varying temperature conditions.

12. The protective shield of claim 11 in which said base has a bore formed therein and a locking pin seated in said bore, said slot being provided by the wall of said bore and the exterior of said locking pin.

13. The protective shield of claim 11 in which said base has a longitudinal bore formed therein and a locking pin seated in said bore, said slot being provided by the wall of said bore and the exterior of said locking pin.

14. The protective shield of claim 1 in which said gas delivery device is a metering tube disposed in said plenum, said metering tube having a porous wall for diffusion of the gas through said porous wall into said plenum.

15. The protective shield of claim 1 in which said gas delivery device is a conduit disposed in said plenum, said

conduit extending through one of said end walls and mounted from the exterior thereof to said one of said end walls.

16. The protective shield of claim 15 in which said end wall includes a gas supply fitting connectable to an exterior gas source and a passageway formed therein for the delivery of the inert gas from said gas supply fitting to said conduit.

17. A protective shield for chemical vapor deposition systems comprising:

a frame assembly including a pair of spaced end walls and a pair of side walls extending between and mounted to said end walls; and

first and second injector shield bodies carried by said frame assembly, said injector shield bodies being positioned to define a first surface of said protective shield positionable adjacent an injector, said injector shield bodies being spaced apart to define an injection port therebetween for the flow of reagents from the injector through said protective shield, said injector shield bodies being spaced from said side walls to define first and second exhaust ports therebetween, said exhaust ports being connectable with exhaust vents positioned on opposite sides of the injector;

first and second shunt shield bodies carried by said frame assembly, said shunt shield bodies being spaced from said injector shield bodies and positioned to define a second surface of said protective shield opposite said first surface, said first and second shunt shield bodies being spaced apart to define an outlet port therebetween for the flow of reagents through said protective shield;

said injector shield bodies and said shunt shield bodies each including a base, a perforated sheet carried by said base, a plenum partially defined by between said base and said perforated sheet, and a gas delivery device for delivering an inert gas to said plenum at a flow rate such that the gas diffuses through said perforated sheet.

18. The protective shield of claim 17 in which said shunt shield bodies extend between and are spaced from said injector shield bodies and the associated one of said side walls to form a first exhaust passageway between each of said injector shield bodies and said shunt shield bodies and a second exhaust passageway between each of said second shield bodies and said side walls.

19. The protective shield of claim 17 in which said shunt shield bodies each include a bottom outlet port coupled to said plenums thereof for the flow of the inert gas through said shunt shield bodies to form an inert gas barrier zone below said second surface on opposite sides of said outlet port.

20. The protective shield of claim 17 in which said injector shield bodies and said shunt shield bodies each have spaced ends and said end walls are shaped to mate with the ends of said shield bodies to hold said shield bodies in said frame assembly.

21. The protective shield of claim 20 in which said end walls have slots configured to mate with the ends of said shield bodies formed therein and the ends of said shield bodies are seated in said slots, said ends of said shield bodies being movable within said slots as said shield bodies expand and contract under varying temperature conditions.

22. The protective shield of claim 17 in which said perforated sheet is held by said base such that said perforated sheet is movable relative to said base during expansion and contraction of said perforated sheet under varying temperature conditions.

23. The protective shield of claim 22 in which said base has a slot formed therein and said perforated sheet is seated in said slot and movable within said slot during expansion and contraction of said perforated sheet under varying temperature conditions.

24. The protective shield of claim 17 in which said gas delivery device is a metering tube disposed in said plenum, said metering tube having a porous wall for diffusion of the gas through said porous wall into said plenum.

25. The protective shield of claim 17 in which in which said gas delivery device is a conduit disposed in said plenum, said conduit extending through one of said end walls and mounted from the exterior thereof to said one of said end walls.

26. The protective shield of claim 25 in which said end wall includes a gas supply fitting connectable to an exterior gas source and a passageway formed therein for the delivery of the inert gas from said gas supply fitting to said conduit.

27. An atmospheric pressure chemical vapor deposition system comprising:

a plurality of processing chambers each having an injector therein for injecting reagents into said processing chamber and exhaust vents positioned on opposite sides of said injector;

a conveyor for transporting substrates through said processing chambers along a process path;

a plurality of buffer chambers isolating said processing chambers from the rest of the process path;

a muffle enclosing said processing chambers, said buffer chambers and the process path of said conveyor;

a protective shield mounted in said processing chambers for protecting the surface of said injector and the inlets of said exhaust ports, said protective shield including injector shield bodies positioned adjacent said injector, shunt shield bodies spaced from said injector shield bodies, an inlet port between said injector shield bodies and outlet ports between said shunt shield bodies for the flow of reagents through said protective shield, said shunt shield bodies each including a plenum filled with an inert gas and a bottom outlet port coupled to said plenum for delivering a supply of inert gas below said protective shield to form buffer barriers on opposite sides of said outlet port.

28. The chemical vapor deposition system of claim 27 in which said buffer chambers each have at least one by-pass duct for the removal of excess gas from said muffle and in which the rate at which gases are removed from the processing chamber through said exhaust vents is less than the rate at which gases are introduced to the processing chamber such that a portion of said barrier gas injected through said bottom outlet ports of said shunt shield bodies is removed from said muffle through said by-pass ducts such that no gas from said buffer chambers has to enter said processing chambers.

29. The chemical vapor deposition system of claim 27 in which said protective shield includes a peripheral frame and said shunt shield bodies and said injector shield bodies are held within said peripheral frame such that said shunt shield bodies and injector shield bodies and their said perforated sheets are movable relative to each other and within said peripheral frame during expansion and contraction of said shunt shield bodies and said injector shield bodies and perforated sheets under varying temperature conditions.

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US006059885A

United States Patent [19]**Ohashi et al.**[11] **Patent Number:** **6,059,885**[45] **Date of Patent:** **May 9, 2000****[54] VAPOR DEPOSITION APPARATUS AND METHOD FOR FORMING THIN FILM**

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[73] **Assignees:** Toshiba Ceramics Co., Ltd.; Toshiba Kikai Kabushikikaisha, both of Tokyo, Japan

[21] **Appl. No.:** 08/991,407

[22] **Filed:** Dec. 16, 1997

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Dec. 19, 1996	[JP]	Japan	8-354381

[51] **Int. Cl.⁷** **C23C 16/00**

[52] **U.S. Cl.** **118/730; 118/715**

[58] **Field of Search** **118/715, 730; 204/298.7, 298.28**

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[57]**ABSTRACT**

A vapor deposition apparatus includes a cylindrical hollow reactor having gas supply ports at its upper portion and an exhaust port at its bottom portion. A rotational substrate holder, which seats a wafer substrate, is concentrically placed inside the reactor. The reactor has a straightening vane having gas holes concentrically positioned at its upper portion. Reaction gas is supplied into the reactor to form a thin film on the surface of the wafer substrate on the rotational substrate holder by vapor deposition. In one embodiment, the straightening vane is configured so that the flow rate of the reaction gas in the center portion covering the area of the wafer substrate and the gas flow rate of the reaction gas in the outer portion of the center portion are different from each other. In another embodiment, the reactor is sectioned into upper and lower portions. The inner diameter of the upper portion is smaller than the inner diameter of the lower portion. A link portion connects the lower end of the upper portion and the upper end of the lower portion. The link portion is provided with straightening gas flow-out holes. The rotational substrate holder is positioned below the lower end of the upper portion of the reactor by a predetermined height difference.

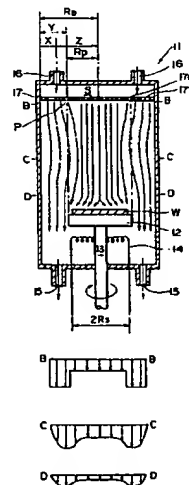
25 Claims, 10 Drawing Sheets

Fig. 1A

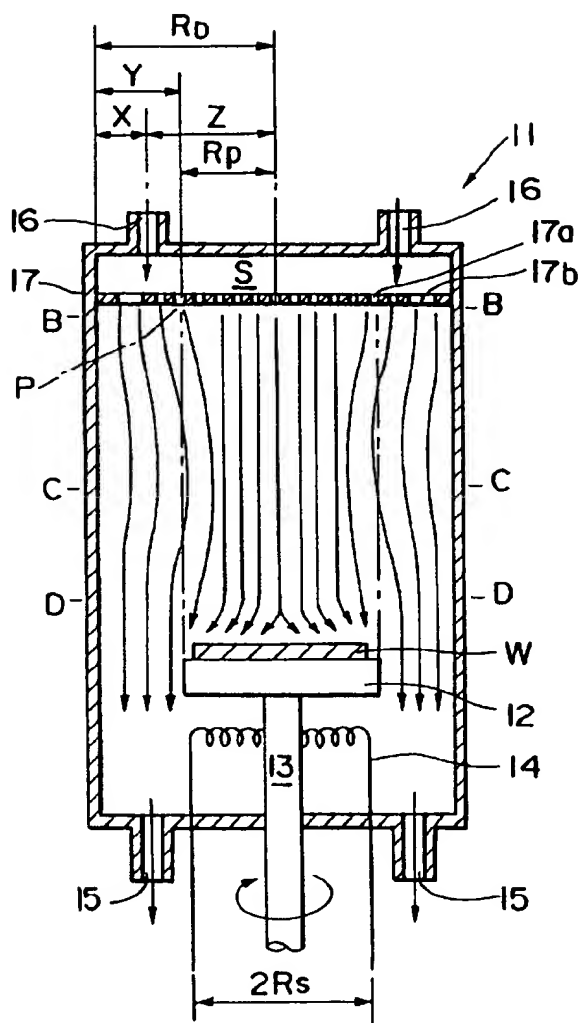


Fig. 1B

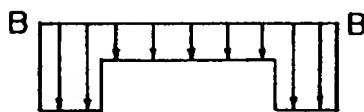


Fig. 1C

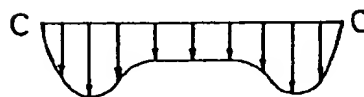


Fig. 1D



Fig. 2

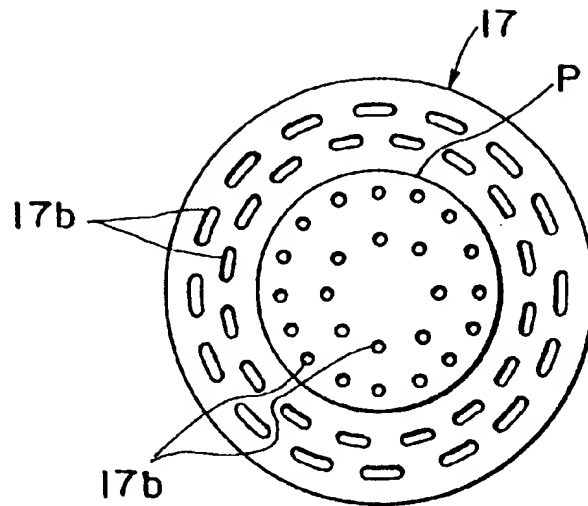


Fig. 3

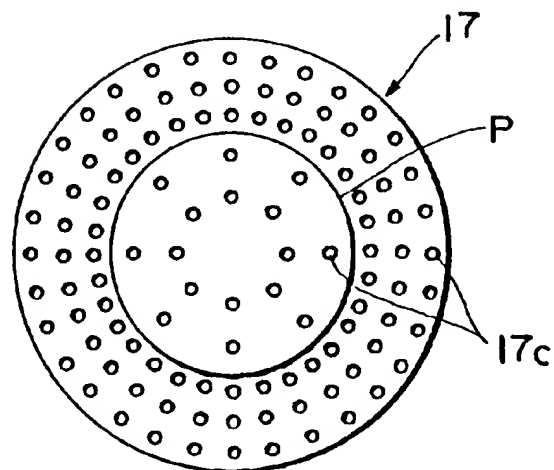


Fig. 4

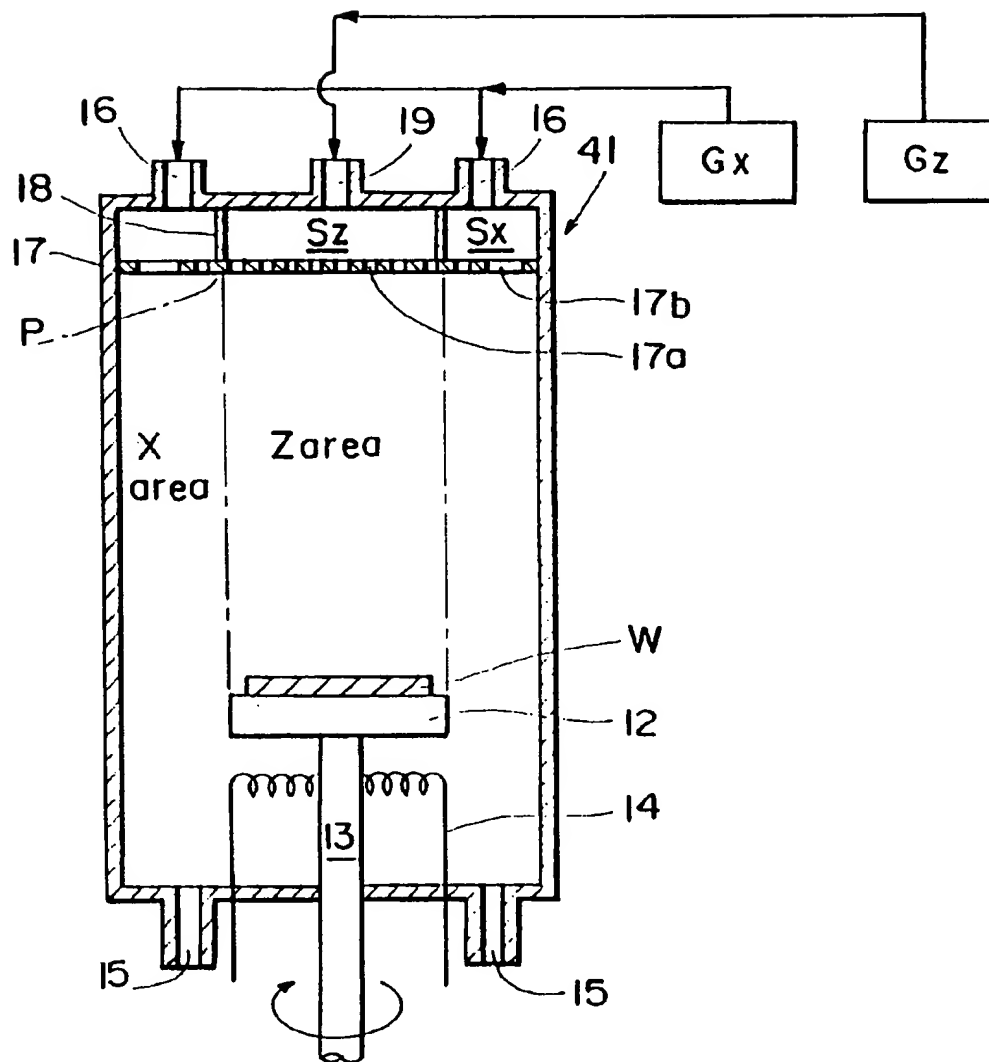


Fig. 5

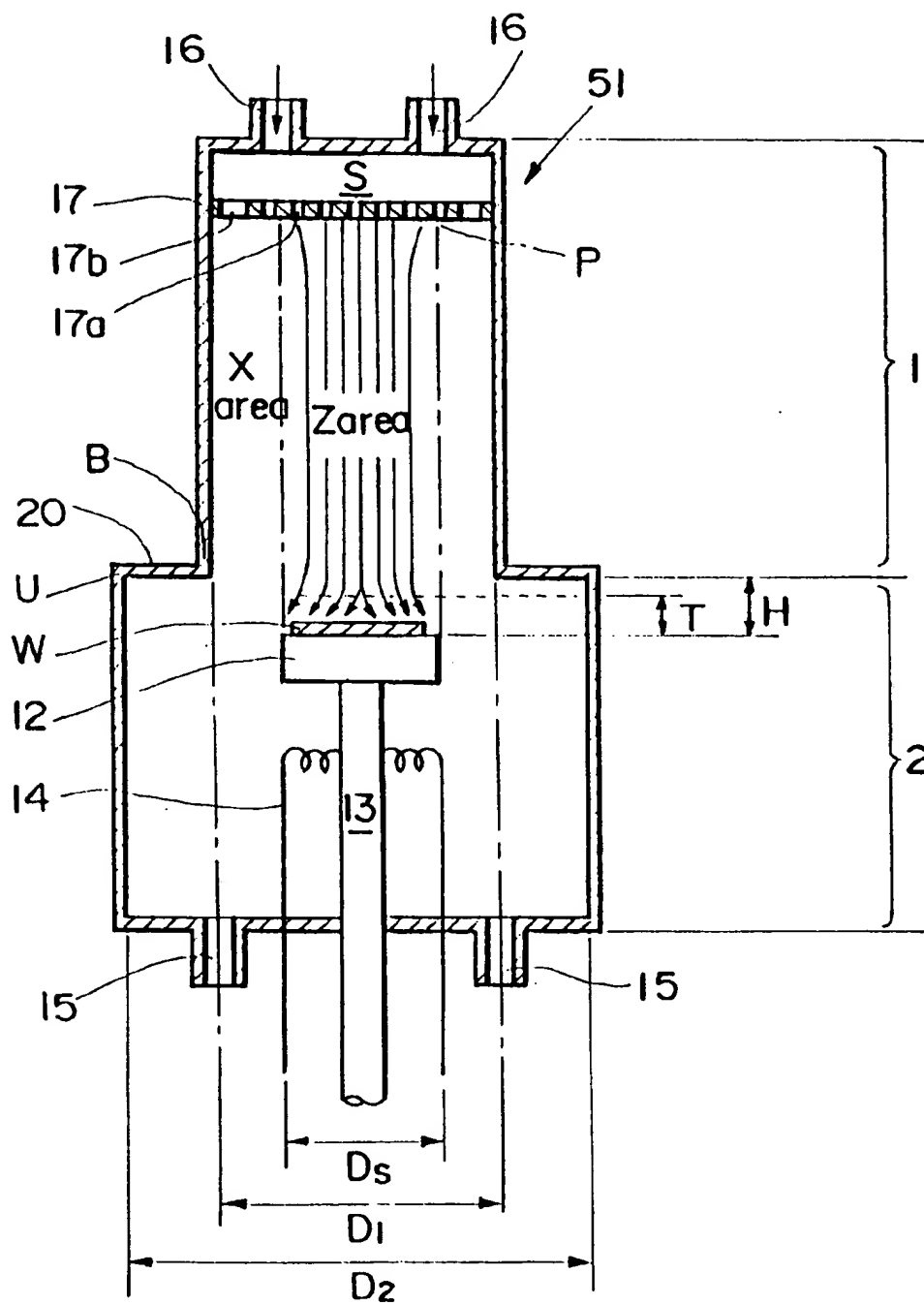


Fig. 6

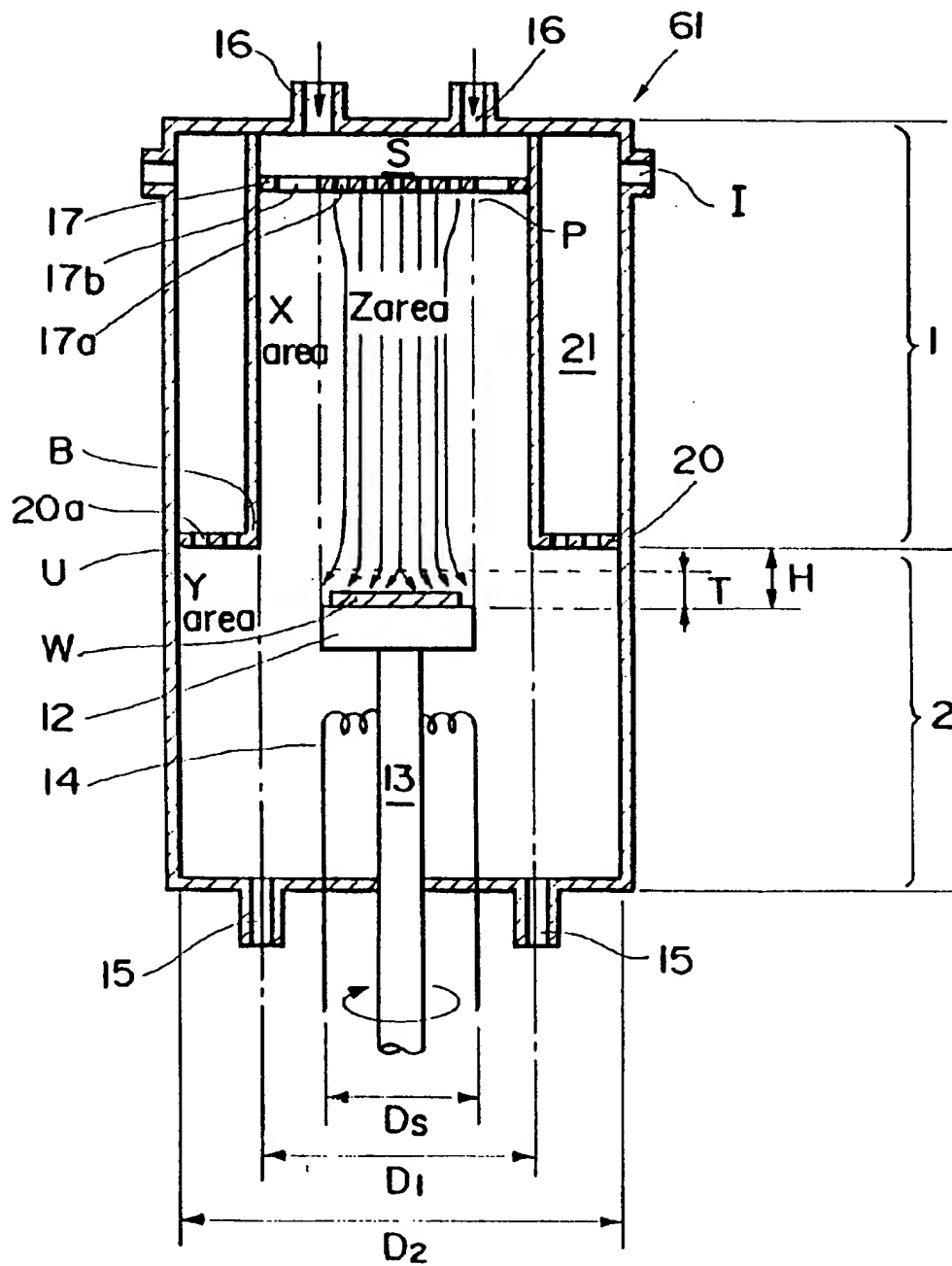


Fig. 7

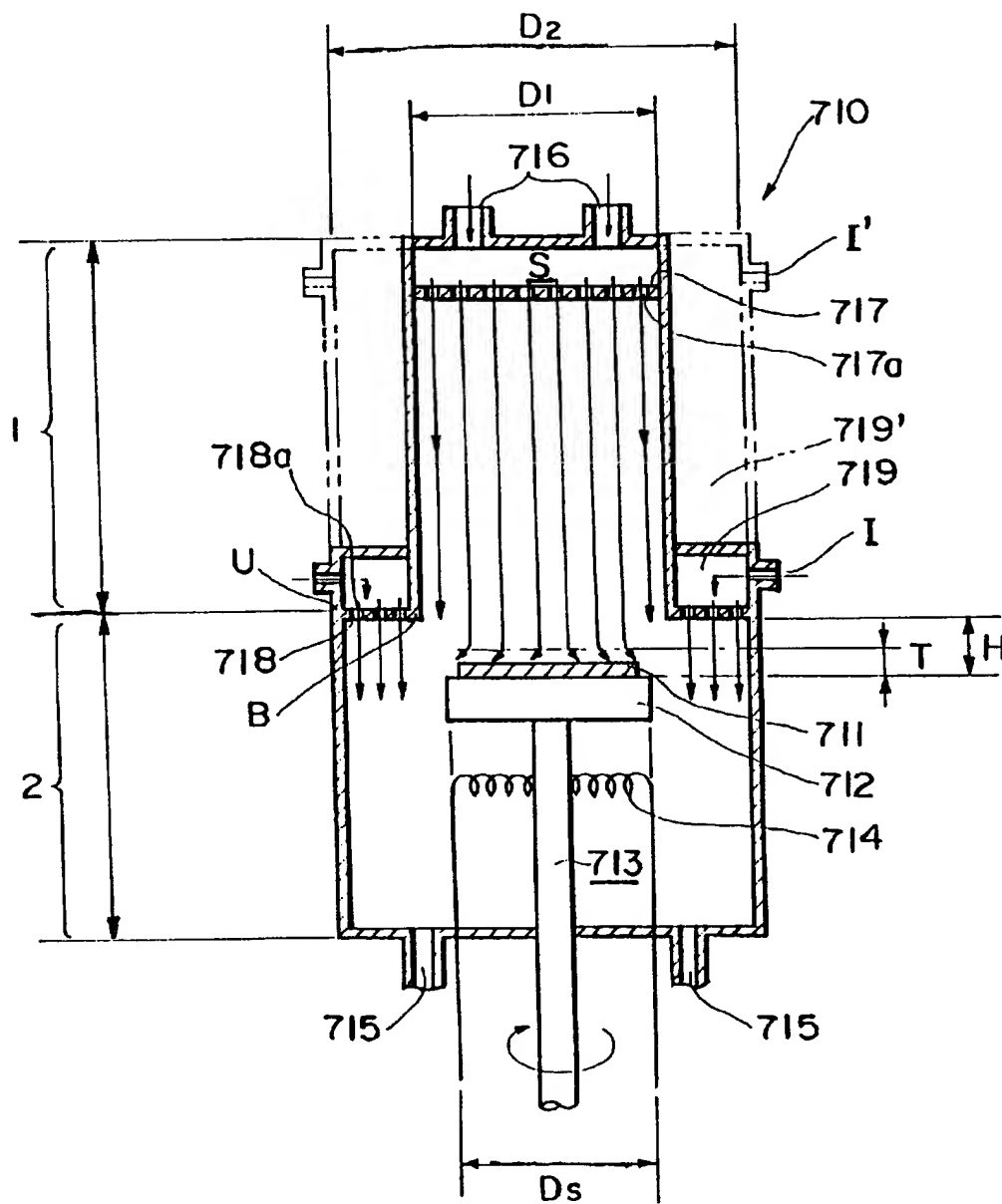


Fig. 8

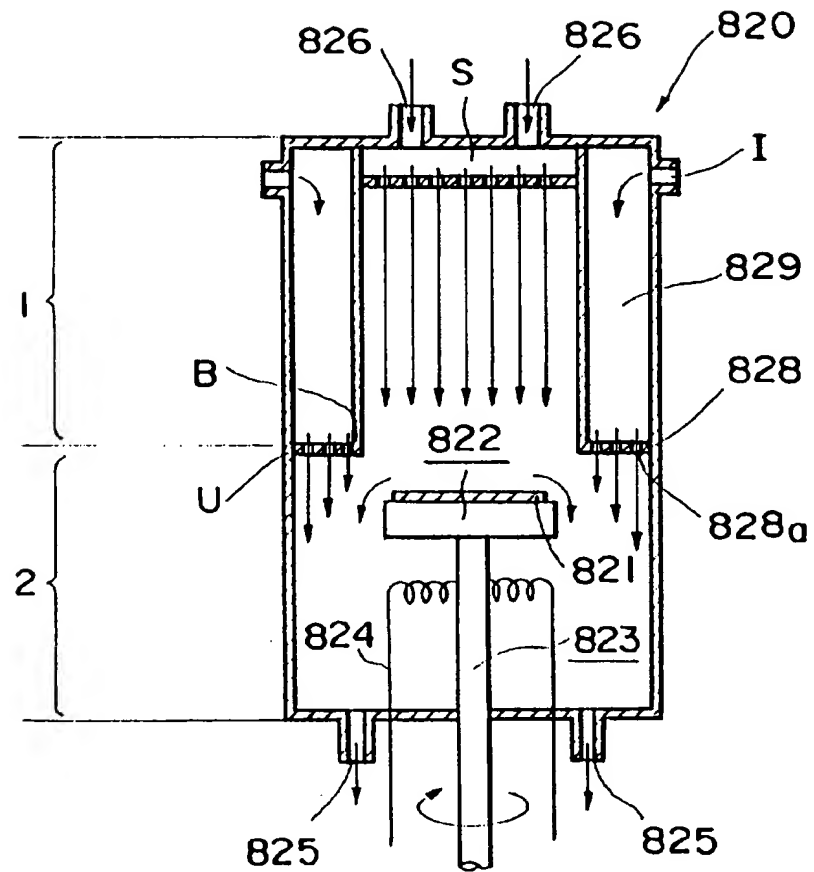


Fig. 9

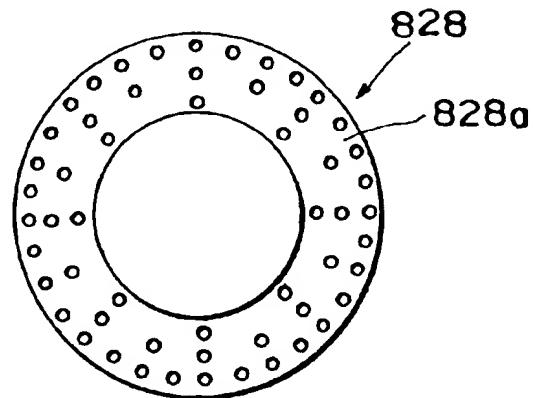


Fig. 10

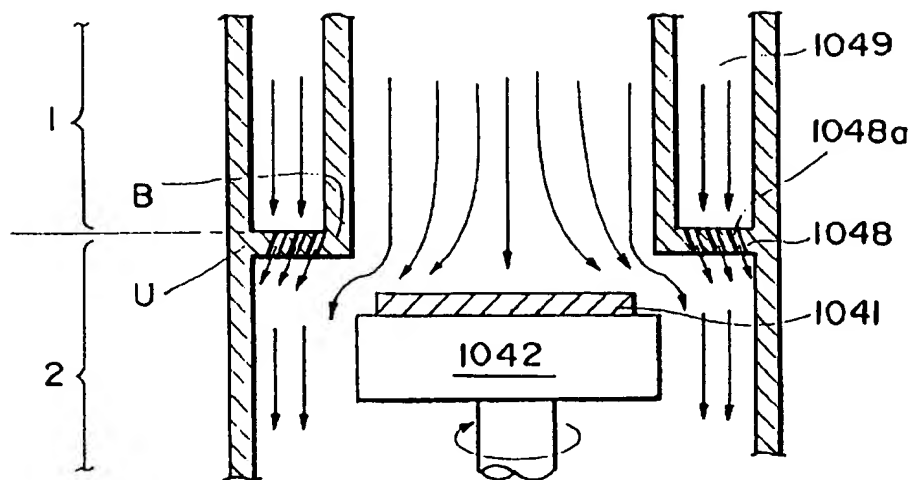


Fig. 11

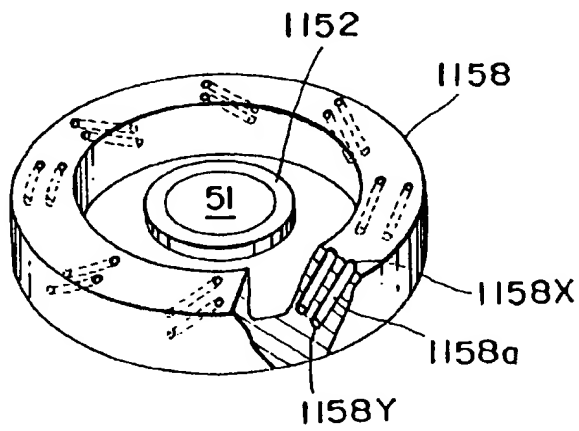


Fig. 12

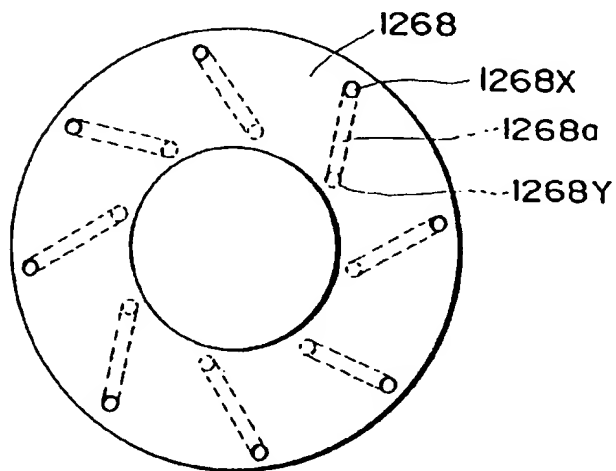


Fig. 13

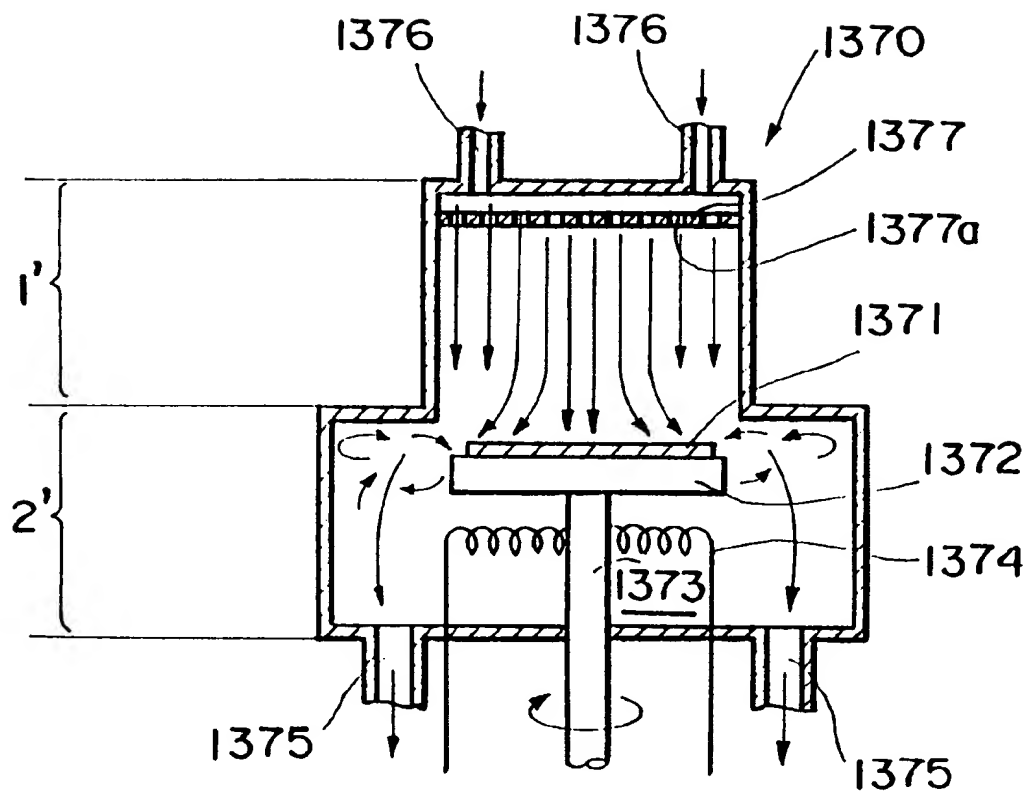
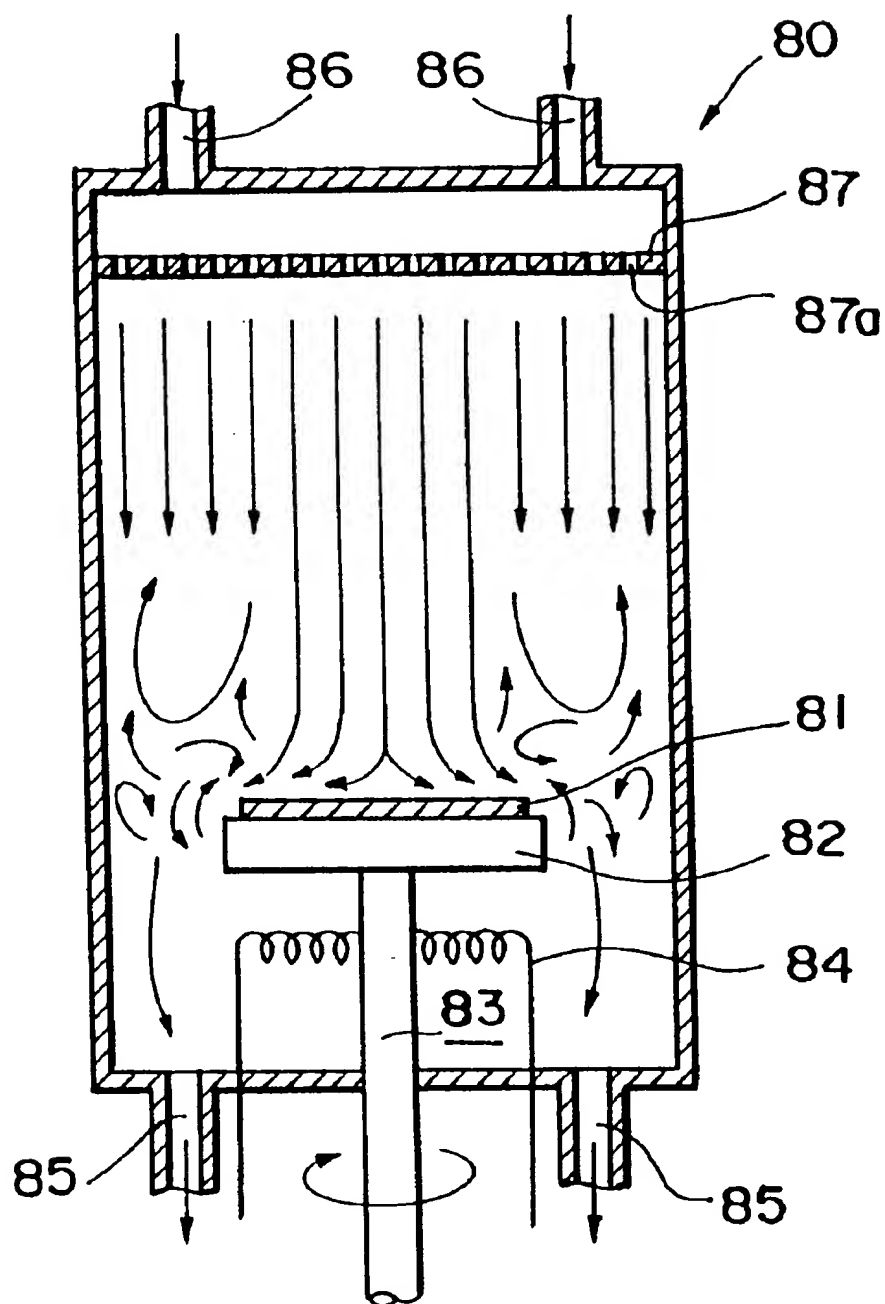


Fig. 14
PRIOR ART



VAPOR DEPOSITION APPARATUS AND METHOD FOR FORMING THIN FILM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates vapor deposition apparatus and method for forming a thin film, and more particularly to vapor deposition apparatus and method which are applied to a process for manufacturing a semiconductor wafer substrate to which high quality is required, and which can suppress occurrence of contaminants such as particles, etc. in vapor phase and deposits on the wall of a reactor to thereby form a thin film having uniform film thickness, so that a homogeneous semiconductor wafer having no dispersion in resistance value and little crystal defect.

2. Description of the Related Art

FIG. 14 shows a conventional vapor deposition apparatus for forming a thin film. In FIG. 14, a rotational substrate holder 82 for mounting a wafer substrate 81 such as a silicon wafer or the like, a rotational shaft 83 for rotating the rotational substrate holder 82 and a heater 84 for heating are generally disposed at the lower portion in a cylindrical reactor 80, and a rotating motor (not shown) is connected to the rotational shaft 83. Further, plural exhaust ports 85 for exhausting non-reacted gas, etc. are disposed at the bottom portion of the reactor 80 and connected to an exhaust control device (not shown). Further, plural gas supply pipes 86 for supplying raw-material gas and carrier gas into the reactor and a disc-shaped straightening vane 87 are provided at the top portion of the reactor 80. The straightening vane 87 is perforated with many holes 87a for regulating flow of gas.

The conventional vapor deposition apparatus is constructed as described above, and the substrate 81 mounted on the rotational substrate holder 82 which is rotated at a predetermined rotational number by the rotation of the motor is heated to a predetermined temperature by the heater 84 while rotated. At the same time, reaction gas such as raw-material gas, carrier gas, etc. are introduced through the plural gas supply pipes 86 into the reactor 80 to make the momentum of the gas and the pressure distribution uniform, and then passed through the many holes 87a of the straightening vane so that the gas flow-rate distribution in the reactor is uniform, whereby the reaction gas is uniformly supplied onto the wafer substrate 81 on the rotational substrate holder 82 to grow a thin film in vapor phase.

In the vapor deposition apparatus for forming a thin film on a semiconductor wafer as described above, various proposals have been made to prevent occurrence of particles and adhesion of deposits to the inner wall of the reactor due to the thin film forming gas, and also to prevent occurrence of crystal defects due to some troubles in a thin film forming process to thereby obtain a wafer having a thin film which is homogenous and uniform in film thickness. For example, in Japanese Laid-open Patent Application No. Hei-5-74719, the supply flow amount of the raw-material gas is controlled to a predetermined value to prevent the temperature variation in the reactor, thereby suppressing crystal defects. In Japanese Laid-open Patent Application No. Hei-5-90167, the raw-material gas amount, the pressure in the reactor, the rotational number of the rotational substrate holder, etc. are controlled to predetermined values so that the in-plane temperature distribution of the wafer substrate in the thin film forming process is made uniform, thereby preventing slip. In Japanese Laid-open Patent Application No. Hei-6-216045, a part of the inner wall of the reactor in which deposits are liable to occur is provided with a shielding pipe

while the inner peripheral surface thereof is kept smoothened, thereby facilitating a cleaning work of the reactor after the thin film forming operation is performed and also the gas flow is kept to a laminar flow state to form a homogenous thin film. Further, in Japanese Laid-open Patent Application No. Hei-7-50260, a method of introducing the raw-material gas and the carrier gas into the reactor is set to a predetermined one to thereby make uniform the gas momentum and the gas pressure, whereby the raw-material gas, etc. are supplied onto the substrate at a uniform flow rate to make the film thickness uniform.

However, the various proposed conventional vapor deposition apparatuses as described above have not yet been capable of sufficiently preventing troubles such as the occurrence of the crystal defect, the adhesion of particles on a wafer substrate on which a thin film is formed, etc. Further, particularly, following recent ultra-high integration of semiconductors, higher quality has been increasingly required to wafer substrates, and reduction in quality due to a slight defect on a thin-film formed wafer substrate induces a critical problem in many cases.

SUMMARY OF THE INVENTION

In view of the problem in reduction in quality of a wafer substrate on which a thin film is formed by vapor deposition according to the conventional vapor deposition apparatus as described above, the present invention has been implemented to solve the above problem. First, the inventors of this applicant have made detailed considerations on the phenomena occurring in the conventional vapor deposition apparatuses. As a result, they have observed such a phenomena that lots of particles adhere to the wall of the reactor, and found out that this phenomenon shorts the maintenance cycle, and the particles adhering to the wall of the reactor also adhere to a wafer substrate to cause crystal defects or directly cause the reduction in quality of the wafer substrate.

From the above knowledge, in order to further find out the cause of the phenomenon that lots of particles adhere to the wall of the reactor, the inventors have also made considerations on the flow of raw-material gas in the reactor, etc. As a result, it has been found out that the following phenomenon occurs in the reactor.

That is, (1) in the conventional reactor, reaction gas such as silicon raw-material gas, etc. which are introduced from the top portion of the reactor and supplied onto a wafer substrate 81 at a uniform flow rate, reaches the vicinity of the wafer substrate 81 at the lower portion of the reactor 80 which is heated to a high temperature from the upper portion thereof by a heater 84, and heated therein. As a result, as indicated by an arrow of FIG. 14, an upward-moving stream of the reaction gas occurs to induce a blow-up phenomenon of the reaction gas along the wall of the reactor, so that an eddy flow of gas occurs. (2) Since the heated reaction gas flows upwardly, the temperature of the overall area in the reactor 80 is also increased to promote uniform nucleus formation of thin-film forming raw-material gas in vapor phase, so that occurrence of particles is increased in vapor phase. (3) Further, when the gas eddy flow occurs, dopant in the reaction gas may be re-doped at the outer periphery portion of the wafer substrate 81 on the rotational substrate holder 82, resulting in uniformity of the in-plane resistance value distribution of the wafer substrate thus obtained. (4) Still further, aside from the occurrence of the gas eddy flow, the blow-up phenomenon in which the reaction gas flowing down to the vicinity of the wafer substrate upwardly moves in the reactor produces so-called "disturbance of gas" in

which the gas flow becomes complicated at the outer peripheral side of the rotational substrate holder 82. The disturbance of the gas flow promotes reaction of non-reacted gas which should be exhausted from an exhaust port 85, so that thin film components are deposited on the outer peripheral surface of the rotational substrate holder 82, and particles adhere to the wall of the reactor which confronts the outer peripheral surface of the rotational substrate holder 82.

The occurrence of the gas eddy flow and the disturbance of the gas flow which induce various troubles can be suppressed to some extent by setting the gas flow rate in the shaft direction of the rotational substrate holder to an extremely high value, for example, about 1 m/s or more. However, in order to satisfy this condition, a large amount of carrier gas must be supplied, and this is industrially impractical.

Further, the inventors have attempted that in order to suppress the occurrence of the gas eddy flow, the upper portion of the reactor is set to be narrower in diameter than the lower portion of the reactor to narrow the space in which the high temperature reaction gas flows upwardly and prevent the occurrence of the gas eddy flow. In this case, the particle adhesion, etc. at the upper portion of the reactor, etc. can be prevented. However, as indicated by an arrow in FIG. 13 which schematically shows a vapor deposition apparatus with a reactor having a narrower upper portion, which is used as a comparison example as described later, it is found out that gas eddy flow and gas flow disturbance occurred at a diameter-larger portion of the reactor locating at the outside of the rotational substrate holder. When gas eddy flow or gas flow disturbance occurs at a diameter-larger portion, the area of the reactor where the problems such as the adhesion of the particles to the peripheral wall of the lower portion of the reactor, the adhesion of the thin film components due to reaction of non-reacted gas, etc. is merely varied, and thus it is apparent that such a trouble that the maintenance cycle is shortened, etc. occur.

SUMMARY OF THE INVENTION

Therefore, the inventors have made various studies on the structure of a vapor deposition apparatus for forming a thin film which can suppress occurrence of gas eddy flow and disturbance of gas flow due to ascent of gas flow in a reactor to thereby avoid undesired phenomena such as occurrence of lots of ascending particles, adhesion of lots of particles to the inner wall of the reactor, deposition of thin-film forming components, re-doping of dopant into the outer peripheral portion of the wafer, etc. As a result, the inventors have found out that the above problem could be solved by any of a vapor deposition apparatus having such a structure that a straightening vane having a specific structure is disposed in a specific arrangement so that the gas flow rate is varied between the center portion and the outer peripheral portion in the reactor, and a vapor deposition apparatus having such a structure that a reactor is designed to have an upper portion having a smaller diameter and a lower portion having a larger diameter, a straightening (rectifying) gas flow-out hole is provided at the link portion between the upper portion and the lower portion which are different in diameter, the straightening gas is supplied through the flow-out hole, and the ratio of the inner diameter of the upper portion of the reactor, the inner diameter of the lower portion of the reactor and the diameter of the rotational substrate holder is set to a predetermined value to rectify the disturbance of gas flow in the reactor containing the diameter-larger portion, and have implemented the present invention on the basis of the above knowledge.

Accordingly, an object of the present invention is to provide a vapor deposition apparatus for forming a thin film which can prevent occurrence of lots of ascending particles, adhesion of lots of particles to the wall of a reactor and deposition of thin film forming components to thereby suppress occurrence of crystal defects on a wafer substrate and re-doping of dopant into the outer peripheral portion of the wafer, thereby obtaining a high-quality wafer substrate on which a thin film having little crystal defect and an uniform thickness is laminated.

Further, another object of the present invention is to provide a method of forming a high-quality thin wafer substrate having little defect and an uniform film thickness with the above vapor deposition apparatus by vapor deposition.

According to a first aspect of the present invention, a vapor deposition apparatus for forming a thin film which includes plural reaction gas supply ports at the top portion of a hollow reactor, an exhaust port at the bottom portion of the reactor, a rotational substrate holder which is provided inside the reactor and adapted to mount a wafer substrate, a ceiling portion and a space area at the upper portion in the reactor, and a straightening vane having plural gas holes formed therein, thereby forming a thin film on the surface of a wafer substrate on the rotational substrate holder by supplying the reaction gas into the reactor, is characterized in that the gas flow rate at the center portion and the gas flow rate at the peripheral portion in the reactor are set to be different.

In the vapor deposition apparatus of the first aspect of the present invention, it is preferable that the straightening vane is brought into close contact with the peripheral wall of the reactor, and the opening degree of the gas hole is set to be larger in an outer area extending radially outwardly from the outer peripheral edge of the orthogonal projection shape of the rotational substrate holder which is obtained by orthogonally projecting the rotational substrate holder onto the straightening vane in the radial direction than that in the other area, so that the gas flow rate is different between the center portion and the outer peripheral portion in the reactor. Alternatively, it is preferable that the outer peripheral edge of the straightening vane and the peripheral wall in the reactor has a gap therebetween, and the outer peripheral edge of the straightening vane is located in the outer area extending radially outwardly from the outer peripheral edge of the orthogonal projection shape of the rotational substrate holder orthogonally projected to the straightening vane in the radial direction so that the gas flow rate is made different between the center portion in the reactor and the outer peripheral portion of the reactor.

In these cases, the outer area has a predetermined interval (gap width) from the inner peripheral wall in the reactor, and the ratio (X/Y) of the interval width (X) and the difference ($Y=R_D-R_P$) of the equivalent radius (R_D) of the straightening vane and the equivalent radius (R_P) of the orthogonal projection shape is preferably set to 0.02 to 1.0, and more preferably to 0.05 to 0.5. Further, it is preferable that the horizontal section of the reactor is circular, and the straightening vane and the rotational substrate holder are disposed concentrically. That is, the opening degree is set to a large value. Further, it is preferable that the interval width between the inner wall of the reactor and the outer area at which the outer peripheral edge of the straightening vane having a gap with the inner periphery of the reactor is located is set to be equal to the difference in radius between the straightening vane and the rotational substrate holder or 0.02 time of the difference or more.

Further, in the vapor deposition apparatus according to the first aspect of the present invention, it is preferable that the space area is divided into at least two sections by a partition member which is located in the outer area extending radially outwardly from the outer peripheral edge of the orthogonal projection shape of the rotational substrate holder orthogonally projected to the straightening vane, and two or more reaction gas supply ports are provided to each of the sections to make the gas flow rate different between the center portion in the reactor and the outer peripheral portion of the reactor. In these cases, the outer area has a predetermined gap width from the inner peripheral wall in the reactor, and the ratio (X/Y) of the interval width or radial distance (X) and the difference ($Y=R_D-R_P$) of the equivalent radius (R_D) of the straightening vane and the equivalent radius (R_P) of the orthogonal projection shape is preferably set to 0.02 to 1.0, and more preferably to 0.05 to 0.5. Further, it is preferable that the horizontal section of the reactor is circular, and the straightening vane and the rotational substrate holder are disposed concentrically. That is, the opening degree is set to a large value. Further, it is preferable that the interval width between the inner wall of the reactor and the outer area at which the outer peripheral edge of the straightening vane having a gap with the inner periphery of the reactor is located is set to be equal to the difference in radius between the straightening vane and the rotational substrate holder or 0.02 time of the difference or more. Still further, it is preferable that an individual reaction gas supply system is connected through the reaction gas supply port every section so that the gas flow rate is made difference between the center portion in the reactor and the outer peripheral portion of the reactor.

Still further, in the vapor deposition apparatus of the present invention, the hollow inside of the reactor is sectioned into upper and lower portions which are difference in equivalent inner diameter, and the equivalent inner diameter of the upper portion is set to be smaller than the equivalent inner diameter of the lower portion while the lower end of the upper portion and the upper end of the lower portion are connected to each other so that the hollow insides thereof are continuous with each other.

Further, according to the present invention, there is a thin film vapor deposition method in which the reaction gas is passed through the straightening vane to be straightened (rectified) by using the thin film vapor deposition apparatus of the first aspect, and the reaction gas is supplied onto the wafer substrate on the rotational substrate holder so that the reaction gas flow rate after straightened (rectified) is higher in the outer area than in the other area. In the vapor deposition method, the flow rate ratio (V_x/V_z) of the gas flow rate (V_x) at the outer area and the gas flow rate (V_z) at the other area is set to 5 to 30, and more preferably to 10 to 20.

Further according to the present invention, there is provided a vapor deposition method in which after reaction gas is supplied from the upper side into a hollow reactor, the reaction gas is streamed down onto a wafer substrate which is rotationally supported at the lower side in the reactor to form a thin film on the wafer substrate by vapor deposition, the reaction gas being supplied so that after the reaction gas is straightened (rectified), the gas flow rate (V_x) at the peripheral area of the inner wall of the reactor is higher than the gas flow rate (V_z) at the upper area of the wafer substrate. In this vapor deposition method, the flow rate ratio (V_x/V_z) of the gas flow rate (V_x) at the peripheral area of the inner wall of the reactor and the gas flow rate (V_z) at the upper area of the wafer substrate is set to 5 to 30, and more preferably to 10 to 20.

In the vapor deposition apparatus and the vapor deposition method using the same according to the first aspect of the present invention which are constructed as described above, the reaction gas such as raw-material gas, carrier gas, etc. are supplied into the space area through the plural gas supply ports to make uniform the momentum and the pressure distribution of the gas, and the gas holes are formed and arranged so that the opening degree of the gas holes of the straightening vane is set to be larger at a predetermined outer peripheral area in the plane of the straightening vane than at the other areas (mainly the center area), thereby increasing the reaction flow rate at the peripheral portion of the inner wall of the reactor at the lower side of the straightening vane. Accordingly, unlike the conventional method, the reaction gas flow reaches to the surface of the wafer substrate on the rotational substrate holder and flows in the radial direction, and then the non-reacted gas smoothly flows from the outer peripheral side of the rotational substrate holder to the exhaust port at the bottom portion of the reactor without forming the ascending flow of the non-reacted gas along the wall of the reactor by the high-speed gas flow on the peripheral side of the inner wall of the reactor. Accordingly, the increase of the temperature of the gas in the reactor is suppressed, the uniform nucleus formation is also suppressed, and the occurrence of particles is prevented, thereby preventing the adhesion of parties to the wall in the reactor, the deposition of thin-film forming components, and formation of crystal defects on the wafer substrate due to adhesion of adhesive particles.

Further, since the smooth gas flow is kept, the dopant can be prevented from being re-doped into the outer peripheral portion of the wafer substrate, and the in-plane resistance value of the wafer is uniform, so that a high-quality thin-film formed wafer substrate can be obtained. The apparatus and the method of the present invention are completely different from the conventional apparatus and method in which the straightening vane disposed in the reactor is designed to have gas holes with uniform opening degree over the overall area so that the uniform flow rate is obtained at the lower side of the straightening vane in the reactor, and it is the first time that they have been proposed by the present invention.

Further, according to a second aspect of the present invention, there is provided a vapor deposition apparatus including plural reaction gas supply ports at the top portion of a hollow reactor, an exhaust gas at the bottom portion thereof, a rotational substrate holder for mounting a wafer substrate in the reactor, and a straightening vane having plural holes at the upper portion of the reactor, and in which the reaction gas is supplied into the reactor to form a thin film on the surface of the wafer substrate on the rotational substrate holder by vapor deposition, characterized in that the hollow inside of the reactor is divided into upper and lower portions which are different in inner diameter, the equivalent inner diameter of the upper portion is set to be smaller than the equivalent inner diameter of the lower portion, the lower end of the upper portion and the upper end of the lower portion are connected to each other by a link portion to make the upper and lower portions of the hollow inside of the reactor continuous with each other, the link portion is provided with a straightening (rectifying) gas flow-out hole, and the rotational substrate holder is located at a position which is lower than the lower end of the upper portion in the lower portion of the reactor by a predetermined height.

In the vapor deposition apparatus of the second aspect of the present invention, it is preferable that a space portion for hermetically enveloping the straightening gas flow-out hole

and a straightening gas supply port is provided to the space portion. Further, it is preferable that the side surface of the upper portion is perpendicular to the surface of the rotational substrate holder, and also it is preferable that the space portion and the upper portion are designed in a dual annular shape, and the outer sides surface of the space portion is continuous to the upper end of the lower portion through the link portion. Still further, it is preferable that the horizontal section of the hollow inside of the reactor is circular, the diameter of the upper portion (D_1) is larger than the diameter of the wafer substrate, the rotational substrate holder is circular in section and the ratio (D_1/D_s) of the diameter of the upper portion and the diameter of the rotational substrate holder (D_s) is set to 0.7 to 1.2. Further, it is preferable that the ratio (D_2/D_1) of the upper portion diameter (D_1) and the lower portion diameter (D_2) is set to 1.2 or more, and the ratio (D_1/D_s) of the lower portion diameter (D_2) and the rotational substrate holder diameter (D_s) is set to 1.2 or more. Still further, it is preferable that the height difference (H) between the lower end of the upper portion and the rotational substrate holder is larger than the transition layer thickness (T) of the gas flow above the upper surface of the rotational substrate holder, and the transition layer thickness (T) is a calculated value of $3.22(\nu/\omega)^{1/2}$ (ν represents coefficient of kinematic viscosity (mm^2/s), ω represents an angular velocity of rotation (rad/s)), and a part of the link portion and the upper surface of the rotational substrate holder are in the same horizontal plane.

According to the present invention, there is provided a vapor deposition method using the vapor deposition apparatus of the second embodiment in which the reaction gas containing the thin film forming raw-material gas and the carrier gas are supplied from plural reaction gas supply ports and passed through the straightening vane onto the wafer substrate so that the transition layer thickness (T) of the gas flow at the upper portion of the rotational substrate holder is smaller than the height difference (H) between the lower end of the upper portion and the upper surface of the rotational substrate holder, and at the same time straightening (rectifying) gas is introduced through the straightening gas flow-out hole of the link portion. Further, in the vapor deposition method of the present invention, it is preferable that the rotation of the rotational substrate holder is controlled so that the transition layer thickness (T) which is a calculated value of $3.22(\nu/\omega)^{1/2}$ (ν represents coefficient of kinematic viscosity (mm^2/s), ω represents an angular velocity of rotation (rad/s)) is smaller than the height difference (H), and also it is preferable that the ration (G_1/G_c) of the carrier gas flow rate (G_c) and the straightening gas flow rate (G_1) is set to 0.05 to 2.

In the vapor deposition apparatus and method of the second aspect of the present invention thus constructed, occurrence of eddy flow of gas due to the blow-up phenomenon of the reaction gas which occurs along the wall of the reactor in the conventional vapor deposition apparatus can be suppressed by altering the shape of the reactor so that the diameter of the upper portion is set to be smaller than that of the lower portion, thereby eliminating the space in which the eddy flow occurs. At the same time, the increase of the temperature of the vapor phase at the upper portion of the reactor can be prevented, so that the uniform nucleus formation of the raw-material gas for forming thin films of silicon or the like can be suppressed and thus particles occurring in the vapor phase can be reduced. Therefore, there can be prevented the shortening of the maintenance cycle due to the adhesion of particles to the wall of the reactor, the occurrence of crystal defects due to adhesion of

particles to the wafer, and the deterioration in quality of wafers due to direct adhesion of particles thereto. Further, the suppression of occurrence of gas eddy flow enables the gas flow just above the wafer mounted on the rotational substrate holder to smoothly direct from the center of the wafer to the outer peripheral portion in parallel to the wafer surface. Therefore, no re-doping of the dopant in vapor phase at the outer peripheral portion of the substrate occurs, and a high-quality thin-film formed wafer substrate having an uniform in-plane resistance distribution can be obtained. Still further, the upper portion of the reactor is narrowed, and thus the gas flow rate in the direction of the shaft of the rotational substrate holder can be increased by a relatively small amount of carrier gas, so that the carrier gas amount can be reduced as compared with the conventional apparatus.

Further, the straightening gas flow-out hole is provided to the link portion for linking the lower end of the small-diameter upper portion of the reactor and the upper end of the large-diameter lower portion to flow out the straightening gas such as hydrogen or the like at a predetermined flow rate, so that the gas flow which occurs above the rotational substrate holder and directs from the center to the outer peripheral portion is straightened (rectified), and there can be prevented the so-called gas flow disturbance at the diameter-enlarged lower portion at the outer peripheral side of the rotational substrate holder due to the design in which the diameter of the upper portion of the reactor is smaller than the lower portion of the reactor. Accordingly, adhesion of particles to the inner wall of the diameter-enlarged link portion and the lower portion of the reactor, and deposition of thin-film forming components can be prevented. Further, the ratio of the diameter of the upper portion of the reactor, the diameter of the lower portion of the reactor and the diameter of the rotational substrate holder can be set to a predetermined value to thereby preventing the ascent of the gas in the reactor and thus occurrence of particles. At the same time, the occurrence of gas eddy flow and the disturbance of gas flow can be prevented. Still further, the particles adhering to the wall of the reactor can be avoided from falling down onto the wafer substrate on the rotational substrate holder.

Further, the rotational substrate holder is disposed at a position which is lower than the lower end of the upper portion of the reactor (corresponding to the upper end of the link portion at the lower portion of the reactor) by a predetermined height, and particularly the height difference is set to be larger than the transition layer thickness of the gas flow which is formed on the upper surface of the rotational substrate holder. Therefore, the lower end of the upper portion prevents the ascent of the gas without disturbing smooth gas flow, and thus there occurs no gas eddy flow and no disturbance of gas flow, so that high-quality thin-film formed wafer substrates with no crystal defect can be obtained. Further, the vapor deposition method of the present invention uses the apparatus of the second aspect of the present invention, the flow rate of introducing the reaction gas, the flow-out rate of the straightening gas from the link portion, the rotational speed of the rotational substrate holder, etc. are controlled so that the height difference between the upper surface of the rotational substrate holder and the lower portion of the lower end of the upper portion of the reactor is set to be larger than the transition layer thickness of the gas flow which is formed on the rotational substrate holder, whereby high-quality thin film formed wafer substrates with no crystal defect can be obtained.

In the present invention, the transition layer is defined as a gas layer in which raw-material gas stream supplied

through the straightening vane flows with a vector directing from the center to the outer peripheral portion on the rotational substrate holder, and the transition layer thickness is defined as the thickness of the gas flow having the vector on the rotational substrate holder.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a sectional view showing an embodiment of a reactor of a thin film vapor deposition apparatus according to a first aspect of the present invention, and

FIGS. 1B to 1D are diagrams showing the gas flow rate distribution in the vertical direction at predetermined positions B, C and D respectively in the apparatus shown in FIG. 1A;

FIG. 2 is a plan view showing a straightening vane used in the reactor of the apparatus of the first aspect of the present invention

FIG. 3 is a plan view showing another straightening vane;

FIG. 4 is a sectional view showing another embodiment of the apparatus of the first aspect of the present invention;

FIG. 5 is a sectional view showing another embodiment of the apparatus of the first aspect of the present invention;

FIG. 6 is a sectional view showing another embodiment of the apparatus of the first aspect of the present invention;

FIG. 7 is a sectional view showing an embodiment of a thin film vapor deposition apparatus of a second aspect of the present invention;

FIG. 8 is a sectional view showing another embodiment of the apparatus of the second aspect of the present invention;

FIG. 9 is a plan view showing a link portion of the apparatus of FIG. 8;

FIG. 10 is a sectional view showing a link portion area of another embodiment of the apparatus of the second aspect of the present invention;

FIG. 11 is a perspective view showing a notch portion of the link portion of another embodiment of the apparatus of the second aspect of the present invention;

FIG. 12 is a plan view showing a link portion of another embodiment of the apparatus of the second aspect of the present invention;

FIG. 13 is a sectional view showing a thin film vapor deposition apparatus which is used as a comparison example; and

FIG. 14 is a sectional view showing a conventional thin film vapor deposition apparatus.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Preferred embodiments according to the present invention will be described hereunder with reference to the accompanying drawings.

First, embodiments of a vapor deposition apparatus of a first aspect of the present invention will be described with reference to the accompanying drawings. However, the present invention is not limited to the following embodiments. In the following description, for convenience's sake, a reactor is designed in a hollow cylindrical shape having a circular horizontal section. However, the horizontal sectional shape of the reactor is not limited to a specific shape, and it may be square or the like. Further, the same is applied to a rotational substrate holder. In general, a hollow cylindrical reactor and a disc-shaped rotational substrate holder are favorably used.

FIG. 1A is a sectional view showing an embodiment of a thin film vapor deposition apparatus of a first aspect of the present invention, and FIGS. 1B to 1D are diagrams showing the gas flow rate distribution in the vertical direction at predetermined positions B, C and D respectively in the apparatus of FIG. 1A. Arrows of FIG. 1A schematically represent gas streams in the apparatus as in the case of FIG. 14. FIG. 2 is a plan view showing a straightening vane disposed in the apparatus of FIG. 1A.

In FIG. 1A and FIG. 2, a reactor 11 is designed substantially in the same construction as the reactor of the conventional vapor deposition apparatus as described above. That is, a rotator 12 for mounting a wafer substrate W thereon is freely rotatably supported at the lower portion in the reactor by a rotational shaft 13, and a heater 14 for heating the rotator 12 and the wafer substrate W mounted thereon is disposed below the rotator 12. The rotational shaft 13 is connected to a rotating motor (not shown). Further, plural exhaust ports 15 for exhausting non-reacted gas, etc. are disposed at the bottom portion of the reactor 11. At the top portion of the reactor 11 are disposed plural gas supply ports 16 for supplying reaction gas containing raw-material gas such as silane (SiH_4), dichlorosilane (SiH_2Cl_2) or the like and carrier gas such as hydrogen (H_2), argon (Ar), helium (He) or the like. A disc-shaped straightening vane 17 having plural small-diameter gas holes 17a and plural large-diameter gas holes 17b formed therein is disposed at the upper portion in the reactor so as to be spaced from the ceiling portion with keeping a predetermined space area S and so as to be disposed in close contact with the inner peripheral surface of the reactor so that the supplied reaction gas is not drifted.

In the present invention, the straightening vane disposed at the upper portion of the reactor serves to streams the reaction gas introduced from the gas supply ports 16 through the many gas holes 17a and 17b into the reactor. In this case, unlike the conventional straightening vane in which the gas holes have an uniform opening degree, the gas holes of the straightening vane of this embodiment are designed so that the opening degree thereof at a predetermined outer area (X area) is set to be larger than that at the other areas, mainly at the center area (hereinafter merely referred to as "center area" or "Z area"). In this case, the ratio of the opening degree of the outer area (O_x) and the opening degree of the center area (O_z) is preferably set to such a value that the flow rate of the reaction gas after the reaction gas is passed and straightened through the gas holes at each area is equal to a rate (V_x/V_z) as described later. Usually, the gas holes in each area are designed so that the ratio of O_x/O_z is equal to 10 to 2600. No restriction is imposed on the shape and location of the gas holes, and they may be suitably determined in accordance with the shape of the reactor and the reaction conditions. For example, as shown in FIGS. 1A and 2, the opening degree may be varied by forming gas holes which are different in opening diameter. In FIG. 1A and 2, the gas holes 17a having a small diameter are disposed at equal intervals in the center area of the straightening vane 17, and the gas holes 17b having a large diameter are suitably disposed in the outer area. As shown in FIG. 2, the opening portion of each large-diameter gas hole 17b is designed to be elongated in the peripheral direction, however, it may be designed as a circular hole or a square hole. Besides, gas holes 17c having the same shape and the same opening diameter may be formed in the straightening vane so that the number of gas holes per unit area in the outer area is larger than that in the center area to make the opening degree of the outer area larger than that of the center area.

Further, in any case, the gas holes 17a formed in the center area of the straightening vane are disposed substantially at equal intervals so that the reaction gas passing through the gas holes 17a of the center area is straightened (rectified) and flows down onto the surface of the wafer substrate W on the rotational substrate holder 12 at a uniform flow rate.

In the straightening vane of the apparatus of this embodiment, the outer area having a larger opening degree represents an area which is located at the outside in the radial direction of the outer peripheral edge P of the orthogonal projection shape obtained by orthogonally projecting the rotational substrate holder 12 disposed at the lower portion of the reactor. That is, the radius R_p of the orthogonal projection shape obtained by orthogonally projecting the disc-shaped rotational substrate holder 12 is equal to the radius (R_s) of the rotational substrate holder 12. The boundary between the outer area and the center area is set to be equal to or smaller than the difference $Y (=R_D - R_p)$ of the radius R_D of the straightening vane and the radius R_p of the orthogonal projection shape. That is, when the boundary between the outer area and the center area has an interval distance (width) X from the wall of the reactor which is in close contact with the straightening vane and a distance Z from the center of the straightening vane, $X \leq Y$. Accordingly, if $X=Y$, $Z=R_p$, and the boundary is coincident with the outer peripheral edge P of the orthogonal projection shape. If $X < Y$, $Z > R_p$, and the boundary is located at the outside in the radial direction of the outer peripheral edge P. Further, the ratio of the interval width X of the outer area and the difference Y is set to 0.02 to 1.0 ($0.02 \leq X/Y \leq 1.0$), and preferably to 0.05 to 0.5. If X/Y is smaller than 0.02, the gas flows up along the wall of the reactor, that is, the blow-up phenomenon of gas flow occurs, and occurrence of gas eddy flow cannot be prevented. On the other hand, if X/Y exceeds 1.0, the outer area having the large-diameter gas holes 17b (i.e., having the larger opening degree) invades into the orthogonal projection shape of the rotational substrate holder 12, and reaction gas flow having a uniform flow rate distribution cannot be obtained in the gas flow path extending to the rotational substrate holder in the reactor, so that any high-quality thin-film formed wafer substrate with no crystal defect cannot be obtained.

In the vapor deposition apparatus of the first aspect of the present invention, the gas holes are formed in the straightening vane disposed at the upper portion in the reactor so that the opening degree at the outer area (X area) is larger than the opening degree at the center area (Z area), and the gas holes in the center area are uniformly arranged so that the reaction gas passing through the gas holes flows down at a uniform flow rate. Accordingly, the reaction gas which is introduced through the plural gas supply ports 16 at the top portion of the reactor is passed and straightened (rectified) through each gas hole of the straightening vane 17, and at the same time the reaction gas flows down at different flow rates between the X area and the Z area. Further, the boundary between the X area having the larger opening degree and the Z area having the smaller opening degree is positionally substantially coincident with the outer peripheral edge P of the orthogonal projection shape obtained by orthogonally projecting the rotational substrate holder, or located at the outside of the outer peripheral edge P toward the wall of the reactor. Therefore, the reaction gas passing through the gas holes 17a which are uniformly arranged substantially above the rotational substrate holder toward the center side from the outer peripheral edge P of the orthogonal projection shape flows down onto the surface of the wafer substrate on the rotational substrate holder 12 at a predetermined uniform

flow rate (flow amount). In addition, the reaction gas passing through the gas holes 17b in the X area which is located at the outside of the outer peripheral edge P of the orthogonal projection shape flows through the gas holes 17b at a flow amount larger (at a flow rate higher) than that of the Z area because the opening degree of the X area is higher than that of the Z area.

By using the vapor deposition apparatus of the first aspect of the present invention thus constructed, the wafer substrate W is mounted on the rotational substrate holder 12, and then the inside of the reactor 11 is evacuated by the exhaust control device which is connected to the exhaust ports 15. Thereafter, the raw-material gas such as silane gas, etc. is supplied into the reactor to adjust the inner pressure of the reactor to 20 to 50 torr. Further, the motor is actuated to rotate the rotational shaft 13 and thus the rotational substrate holder 12, and at the same time the wafer substrate W on the rotational substrate holder 12. At the same time, the wafer substrate W on the rotational substrate holder 12 is heated to about 900 to 1200 degrees Celsius by the heater 14. Further, at the same time, the reaction gas containing the raw-material gas and the carrier gas is supplied into the space area S in the reactor 11 while controlling the flow amount of the gas supplied from the gas supply ports 16. The gas stream which is supplied from the plural gas supply ports 16 into the space area S is uniformed in momentum and pressure distribution, and further flows down while passed and straightened (rectified) through the plural gas holes 17a and 17b which are formed in the straightening vane 17 with the opening degrees corresponding to the respective areas. Further, the reaction gas passed through the straightening vane flows at a flow rate which is determined by the amount of the gas thus supplied and the opening degree of the straightening vane. Further, as described above, in the Z area extending from the outer peripheral edge P of the orthogonal projection shape of the rotational substrate holder to the center of the rotational substrate holder, the gas holes 17a having the same diameter are arranged at equal intervals, so that the reaction gas flows down onto the wafer substrate at the substantially uniform gas flow to uniform form a homogeneous thin film on the wafer substrate by vapor deposition.

As described above, the flow rate of the reaction gas passing through the straightening vane of the reactor is varied between the outer area (X area) and the center area (Z area) which are different in opening degree with the outer peripheral edge P of the orthogonal projection shape of the rotational substrate holder at the boundary thereof, so that the gas flow rate distribution has a gradient in the reactor. For example, as shown in the gas stream distribution diagrams of FIGS. 1A to 1D, the reaction gas flows at a larger gas flow amount and thus flows down substantially vertically at a high flow rate in the X area having the larger opening degree which is near to the inner wall of the reactor. This high flow-rate gas flow which is formed around the inner wall of the reactor can suppress the blow-up phenomenon (i.e., the ascent of the gas stream along the inner wall of the reactor) which is observed in the conventional reactor, and thus occurrence of gas eddy flow can be prevented. Further, the increase of the vapor-phase temperature in the reactor can be prevented because the heated gas does not ascend. Therefore, the uniform nucleus formation of the thin-film formed components of the raw-material gas in the reaction gas can be suppressed, and the particles occurring in the vapor phase in the reactor can be reduced. Accordingly, there can be prevented the disadvantages of the conventional method that the particles occurring in vapor phase adhere to the wall of the reactor, resulting in short-

ening of the maintenance cycle, the particles adhere to a wafer to induce crystal defects, and the particles acts as adhesive particles to directly reduce the quality of the wafer.

Further, when the reaction gas which is supplied through the Z area at the center side of the straightening vane passes through the gas holes 17a which have the smaller opening degree than the X area and are substantially uniformly arranged, the reaction gas at the center area flows substantially vertically down and is supplied onto the wafer substrate at an uniform flow rate which is more moderate than the flow rate of the reaction gas at the X area, thereby an uniform thin film can be formed as in the case of the conventional method. As shown in FIG. 1A, the gas flow at the outermost peripheral portion of the Z area is effected by the reaction gas in the X area which flows at a larger flow rate because this portion is adjacent to the X area, and thus the gas stream at this portion is bent toward the center side as if it is pressed. However, since no gas blow-up phenomenon and no occurrence of gas eddy flow occur in the X area around the inner wall of the reactor, the reaction gas at this portion subsequently flows in the radial direction along the wafer substrate as if it is sucked by the gas stream flowing in the X area together with the reaction gas flowing down substantially vertically in the center portion of the Z area to form the gas flow transition layer, and finally flows to the exhaust ports 15. Accordingly, the gas flow in the radial direction is not disturbed, but smoothened on the wafer substrate, and the gas flows uniformly from the center of the wafer substrate to the outer peripheral portion. Therefore, the dopant can be prevented from being re-doped at the outer peripheral portion of the wafer substrate. Accordingly, the in-plane resistance distribution of the wafer substrate on which a uniform thin film is formed by vapor deposition is also uniform, so that a high-quality wafer substrate can be obtained.

Here, when V_x represents the flow rate of the reaction gas flowing through the gas holes in the outer area (X area) of the straightening vane and V_z represents the flow rate of the reaction gas flowing through the gas holes in the other area (Z area), V_x is set to be larger than V_z by adjusting the opening diameter of the gas holes of the straightening vane and the number of arranged gas holes to suitable values to set the opening degree to a prescribed value. Preferably, the ratio (V_x/V_z) of the flow rate V_z in the X area and the flow rate V_x in the Z area is set to 5 to 30, preferably to 10 to 20. If the flow rate ratio is less than 5, the blow-up phenomenon of the gas flow (i.e., the ascent of the gas flow along the wall of the reactor) and the gas eddy flow occur, and thus this condition is unfavorable. On the other hand, if the flow rate ratio is more than 30, the gas flow rate of the reaction gas in the X area (outer area) around the wall of the reactor is excessive to disturb the gas flow which forms the transition layer in the area extending from the center of the rotational substrate on the rotational substrate holder to the outer peripheral portion. Therefore, this condition is also unfavorable. In the present invention, it is preferable that the gas flow rate of the Z area is generally set to 0.05 to 0.7 m/s. If the gas flow rate is less than 0.05 m/s, not only the gas flow at the outermost portion of the Z area on the rotational substrate holder which is adjacent to the X area is pressed to the center side, but also the gas flow from the center to the outer peripheral portion of the rotational substrate on the rotational substrate holder is disturbed, and thus this condition is also unfavorable. Further, if the gas flow rate exceeds 0.7 m/s, no more effect is obtained.

In the conventional vapor deposition apparatus, the reaction gas flows onto the wafer substrate at a relatively high

flow rate of 0.7 to 1.0 m/s. On the other hand, in the vapor deposition apparatus of the present invention, the reaction gas flows onto the wafer substrate at a flow rate of 0.7 m/s or less, and thus the gas blow-up phenomenon and the gas eddy flow which occur in the conventional method can be prevented. Therefore, it is unnecessary to flow a large amount of carrier gas, and this is extremely industrially practical. In this case, the gas flow rate of the X area may be suitably set in accordance with the ratio (V_x/V_z).

FIG. 4 is a sectional view showing another embodiment of the vapor deposition apparatus of the present invention. In FIG. 4, the vapor deposition apparatus of this embodiment is designed in the same construction as the apparatus of FIG. 1 except that the space area which is formed by the ceiling portion and the straightening vane 17 at the upper portion in the reactor 41 is divided into a peripheral space area S_x and a center space area S_z by a partition plate 18. The same members as shown in FIG. 1A are presented by the same reference numerals, and the duplicative description thereof is omitted.

The partition plate 18 is disposed at the boundary between the outer area (X area) in which the opening degree of the straightening vane shown in FIG. 1A is varied and the other area, that is, at the boundary between the outer area (X area) in which the opening degree is larger and the flow rate of the reaction gas is higher, and other area (Z area) at which the opening degree is smaller and the flow rate of the reaction gas is lower, and the interval width from the peripheral wall of the reactor in the outer area is set to the same as described above. Usually, the partition plate 18 is located near to the outer peripheral edge P of the orthogonal projection shape of the rotational substrate holder 12 to the straightening vane 17. The space area S_x and the space area S_z are separately provided with gas supply ports 16 and a gas supply port 19 respectively. Further, the gas supply ports 16 and the gas supply port 19 are separately connected to different gas supply systems G_x and G_z respectively. Accordingly, the space areas S_x and S_z which are sectioned by the partition plate 18 are separately supplied with the reaction gas containing the raw-material gas, the carrier gas, etc. In short, the reaction gas may be supplied while varying the type of the reaction gas, the mixing ratio if the reaction gas is mixed gas, various supply conditions such as the temperature, pressure, gas flow amount, etc. at the gas supply time. For example, in FIG. 4, the straightening plate 17 is provided with the large-diameter gas holes 17b in the X area and the small-diameter gas holes 17a in the Z area so that the opening degree of the straightening vane is varied with the partition plate 18 at the boundary as in the case of FIG. 1A. Further, in this system, the gas holes may be formed to have a uniform opening degree over the overall area of the straightening vane 17, and the reaction gas containing the thin-film forming raw-material gas and the carrier gas are supplied into the space areas S_x and S_z partitioned by the partition plate 18 at different gas flow amounts (rates) respectively by the gas supply systems G_x and G_z so that after the reaction gas passes through the straightening vane 17, the gas flow rate in the X area of the reactor is higher than that in the Z area. Further, only the carrier gas may be passed through the X area.

FIG. 5 is a sectional view showing another embodiment of the vapor deposition apparatus of the first aspect of the present invention. In FIG. 5, the apparatus of this embodiment is designed in the same construction as the apparatus of FIG. 1A except that the inside of a hollow reactor 51 is divided into an upper portion 1 and a lower portion 2, and the upper portion 1 and the lower portion 2 are designed so

that the upper portion 1 is narrower than the lower portion 2, the inner diameter D_1 of the upper portion is set to be smaller than the inner diameter D_2 of the lower portion ($D_1 < D_2$), and the upper end portion U of the large-diameter lower portion 2 and the lower end portion B of the small-diameter upper portion 1 are connected to each other by a link portion 20 so that the inside space of the reactor is continuous over the upper and lower portions. The same members as shown in FIG. 1A are represented by the same reference numerals, and the duplicative description thereof is omitted.

In the reactor 51 of FIG. 5, the rotational substrate holder 12 is disposed so that the upper surface thereof is located at a position lower than the lower end B of the upper portion of the reactor by a predetermined height (H). The side wall surface of the upper portion 1 of the reactor is usually formed in parallel to the side wall surface of the lower portion 2 and vertically to the upper surface of the rotational substrate holder 12. The link portion 20 between the lower end B of the upper portion and the upper end U of the lower portion is usually formed in the horizontal direction. However, it is not limited to this arrangement. For example, it may be formed in a slant or curved-surface shape. In the reactor 51 thus constructed, as in the case of the reactor 11 of FIG. 11, the gas flow rate in the outer area (X area) in the reactor is set to be higher with the outer peripheral edge portion P of the orthogonal projection shape to the straightening vane 17 of the rotational substrate holder 12, thereby preventing occurrence of the blow-up phenomenon of the gas flow and the gas eddy flow. In addition, since the inner diameter D_1 of the upper portion 1 of the reactor is narrower than the inner diameter D_2 of the lower portion, the blow-up phenomenon of the ascending gas flow can be further suppressed, and the occurrence of the particles in vapor phase can be synergistically suppressed, so that the adhesion of the particles to the inner wall of the reactor and the effect of the adhering particles on the wafer substrate can be prevented. Therefore, the quality of the thin-film formed wafer substrate is improved, the maintenance cycle is lengthened, and this provides remarkable industrial advantages.

In the reactor of FIG. 5, it is preferable that the inner diameter D_1 of the upper portion of the reactor, the inner diameter D_2 of the lower portion and the diameter D_s of the rotational substrate holder 12 have the following relationship. For example, D_1 is larger than the diameter of the wafer, and (1) D_2/D_1 is equal to 1.2 or more ($D_2/D_1 \geq 1.2$). If D_1 is smaller than the diameter of the wafer, the particles which fall down from the inner wall surface of the upper portion 1 of the reactor are liable to adhere to the wafer substrate mounted on the rotational substrate holder 12, so that there is such a trend that crystal defects measured as LPD (wafer surface laser scatterer) increase. Further, it is difficult to perform a contactless temperature measurement based on infrared ray on the outer peripheral portion of the wafer substrate which is usually performed in the vapor deposition process. On the other hand, if D_2/D_1 is larger than 1.2, the blow-up phenomenon of the ascending gas flow can be suppressed even when the gas flow rate between the X area and the Z area is relatively small. (2) the D_1/D_s ratio is equal to 0.7 to 1.2 ($0.7 \leq D_1/D_s \leq 1.2$). If the D_1/D_s ratio is equal to 0.7 to 1.2, the blow-up phenomenon of the ascending gas flow can be suppressed even when the gas flow ratio between the X area and the Z area in the reactor is relatively small. If D_1/D_s is smaller than 0.7, the side surface of the upper portion 1 is excessively proximate to the wafer substrate mounted on the rotational substrate holder 12, and

the particles which fall down from the inner wall surface of the reactor are liable to adhere to the wafer substrate. Therefore, as in the case where D_1 is smaller than the diameter of the wafer substrate, the crystal defects measured as LPD are increased, and the quality of the thin-film formed wafer substrate is reduced. On the other hand, if D_1/D_s is larger than 1.2, no further effect can be improved. (3) The D_2/D_s is equal to 1.2 or more ($D_2/D_s \geq 1.2$). If D_2/D_s is smaller than 1.2, the gas stream in the Z area which flows above the rotational substrate holder 12 hardly flows to the exhaust pipes smoothly. Therefore, the particles adhere to the inner wall of the reactor confronting the outside of the rotational substrate holder 12, and the non-reacted gas is reacted at the lower side of the rotational substrate holder 12 to promote deposition of the thin-film formed components on the inner wall of the lower portion 2 of the reactor, thereby shortening the maintenance cycle.

Further, in the reactor 51 of FIG. 5, the upper surface of the rotational substrate holder 12 is located at a position lower than the lower end B of the upper portion 1 of the reactor by a predetermined height difference H. The height difference H is usually preferably set to be larger than the thickness of a transition layer formed by the gas flow in the Z area above the rotational substrate holder 12, that is, the thickness (T) of the gas layer of the gas flow of the raw-material gas, etc. which are passed through the gas holes 17a of the straightening vane 17 as indicated by arrows in FIG. 5 and has a vector directing from the center to the outer peripheral side above the rotational substrate holder 12. If the height difference H is smaller than the transition layer thickness T, the gas stream which flows from the center of the wafer substrate W in the radial direction above the rotational substrate holder 12 is disturbed by the lower end B of the upper portion 1 of the reactor, and thus the blow-up phenomenon of the ascending gas flow along the side surface of the upper portion 1 of the reactor occurs to thereby promote occurrence of gas eddy flow. Further, the upper surface of the rotational substrate holder 12 is preferably in parallel to the link portion 20 between the upper portion 1 and the lower portion 2 of the reactor.

Further, the transition layer thickness T of the gas flow above the rotational substrate holder 12 is varied mainly in accordance with the type of the atmospheric gas in the reactor, the pressure in the reactor and the rotational number of the rotational substrate holder in a general reactor which has been hitherto used, and it can be calculated from the following equation (1). The equation (1) is generally introduced on the basis of hydrodynamics:

$$T = 3.22(v/\omega)^{1/2} \quad (1)$$

(v represents coefficient of kinematic viscosity (mm^2/s), ω represents an angular velocity of rotation (rad/s)). In this case, the minimum value in the thin film forming process of the vapor deposition apparatus is used as ω . For example, when silane gas is used as the raw-material gas, hydrogen gas is used as the carrier gas and the rotational number of the rotational substrate holder is set to 500 to 2000 rpm (52 to 209 rad/s), the transition layer thickness T is equal to about 5 to 50 mm. Accordingly, it is preferable that the rotational substrate holder is located so that the upper surface thereof is located at a position lower than the lower end B of the small-diameter upper portion 1 of the reactor by a height difference H which is larger than the T value, whereby the gas stream from the center to the outer periphery above the wafer substrate is further smoothed, and there occurs no adhesion of particles of thin-film forming raw material, so

that a uniform thin-film formed wafer having no crystal defect can be formed.

FIG. 6 is a sectional view showing another embodiment of the vapor deposition apparatus of this aspect of the present invention. The apparatus of FIG. 6 has the same construction as the apparatus of FIG. 6 except for the following construction. That is, a reactor 61 is divided into a small-diameter upper portion and a large-diameter lower portion 2, and the link portion 20 between the upper portion 1 and the lower portion 2 is provided with plural straightening (rectifying) gas flow-out holes 20a through which straightening (rectifying) gas flows out. In addition, the upper portion 1 of the reactor is designed in a dual structure so that the link portion 20 having the straightening gas flow-out holes 20a is hermetically enveloped by a hollow annular portion 21, and straightening gas supply ports 1 are provided to the hollow annular portion 21. The same members as shown in FIG. 5 are represented by the same reference numerals, and the duplicative description thereof is omitted.

In the reactor 51 of FIG. 6, the straightening gas for making the non-reacted gas smoothly flow into the exhaust ports 15 may be supplied through the straightening gas flow-out holes 20a which are formed in the link portion 20. The carrier gas is generally used as the straightening gas, and the same gas as the carrier gas which is usually introduced through the gas supply ports 16 of the reactor is supplied. The flow of the straightening gas enables the non-reacted gas to flow to the outer peripheral side of the rotational substrate holder 12 and then be exhausted from the exhaust ports 15 without any gas eddy flow and any gas flow disturbance by a synergistic effect with the high-speed reaction gas in the X area after the reaction gas reaches the wafer substrate W to be supplied for the thin film growth (vapor deposition), so that there occurs no deposition of the thin-film forming components at the lower portion of the reactor and thus the maintenance cycle of the reactor can be lengthened.

In the reactor 61 of FIG. 6, the ratio (V_1/V_X) of the flow rate (V_X) of the reaction gas in the X area and the flow rate (V_1) of the straightening gas from the straightening gas flow-out hole 20a is preferably set to 0.05 to 2 ($0.05 \leq V_1/V_X \leq 2$). By flowing the straightening gas from the straightening gas flow-out hole 20a of the link portion 20, so that the ratio V_1/V_X is set in the above range, the flow of the reaction gas above the rotational substrate holder and the flow of the non-reacted gas into the space at the lower portion of the reactor from the outer peripheral side of the rotational substrate holder are smoothed without any gas eddy flow and any gas flow disturbance, so that a high-quality homogeneous thin-film formed wafer substrate having little crystal defect can be obtained. On the other hand, if V_1/V_X is less than 0.05, no effect cannot be obtained even by introducing the straightening gas from the straightening gas flow-out hole 20a at the large-diameter portion at the lower portion of the reactor which is located at the outside of the rotational substrate holder. Further, if V_1/V_X exceeds 2, the gas flow rate at the large-diameter portion at the outside of the rotational substrate holder 12 is excessively high, and thus the smooth gas flow from the center to the outer peripheral portion on the rotational substrate holder is disturbed, so that any homogeneous thin film having a uniform thickness cannot be grown.

Next, preferred embodiments of a vapor deposition apparatus of a second aspect of the present invention will be described.

FIG. 7 is a sectional view showing an embodiment of the vapor deposition apparatus of the second aspect of the present invention.

In FIG. 7, a reactor 710 is sectioned into an upper portion 1 and a lower portion 2, and the upper portion 1 is designed to be narrower than the lower portion 2. That is, the inner diameter D_1 of the upper portion 1 is set to be smaller than D_2 ($D_1 < D_2$). No restriction is imposed on the ratio of the height H_1 of the upper portion and the height H_2 of the lower portion, that is, the section rate of the reactor. The section rate of the reactor may be set to such a suitable value that the rotational substrate holder, etc. can be disposed at the lower portion 2. Usually, the ratio $H_{1/2}$ is set to 0.5 to 2.0. The upper end portion U of the large diameter lower portion 2 and the lower end portion B of the small-diameter upper portion 1 are linked to each other by a link portion 718, and however, the hollow inner space of the reactor is continuous over the upper and lower portions although the upper and lower portions are different in inner diameter. Further, the side wall surface of the upper portion 1 of the reactor is usually vertically formed in parallel to the side wall surface of the lower portion 2 and also vertically to the upper surface of the rotational substrate holder. The link portion 718 between the lower end B of the upper portion 1 and the upper end U of the lower portion 2 is usually formed horizontally, however, it is not limited. For example, it may be formed in a slant or curved-surface shape. The link portion 718 of the reactor is provided with plural straightening gas flow-out holes 718a for through which the straightening gas flows out.

In FIG. 7, a rotational substrate holder 712 for mounting a wafer substrate 711 is freely rotatably supported by a rotational shaft 713 at the large-diameter lower portion 2 of the reactor, and a heater 714 for heating the rotational substrate holder 712 and the wafer substrate 711 mounted thereon is provided at the lower side of the rotational substrate holder 712. The rotational substrate holder 712 is located at a lower position so as to keep a predetermined height difference (H) from the lower end B of the upper portion of the reactor. The rotational shaft 713 is connected to a rotating motor (not shown). Further, plural exhaust ports 715 for exhausting non-reacted gas, etc. are provided at the bottom portion of the reactor 710. Further, plural reaction gas supply ports 716 are provided at the top portion of the upper portion 1 of the reactor, and reaction gas containing raw-material gas of silane (SiH_4), dichlorosilane (SiH_2Cl_2) or the like and carrier gas such as hydrogen (H_2), helium (He), argon (Ar) or the like are introduced from the reaction gas supply ports 716. A disc-shaped straightening vane 717 having plural holes 717a formed therein is provided at the upper side of the upper portion 1 of the reactor so as to keep a predetermined space area S from the top portion of the reactor and be in close contact with the inner peripheral surface of the upper portion of the reactor so that the supplied gas does not form any drift path.

Further, the straightening gas for making smooth the flow of the non-reacted gas to the exhaust ports 715 is introduced from the straightening gas flow-out holes 718a formed in the link portion 718. The carrier gas is generally used as the straightening gas. Usually, the same gas as the carrier gas supplied from the gas supply ports 716 at the top portion of the reactor is introduced. Accordingly, after the reaction gas reaches the wafer substrate 711 to be supplied for the growth of a thin film, the non-reacted gas can smoothly flow out from the outer peripheral side of the rotational substrate holder 712 and be exhausted from the exhaust ports 715 without producing any gas eddy flow and any gas flow disturbance. No restriction is imposed on the way of introducing the straightening gas from the straightening gas flow-out ports 718a insofar as the straightening gas can be

uniformly introduced from each of the straightening gas flow-out holes 718a. For example, an introducing pipe may be provided to each straightening gas flow-out hole 718 to individually introduce the straightening gas from each hole 718. Further, as shown in FIG. 7, the straightening gas flow-out holes 718a may be hermetically enveloped on the link portion 718 to provide a straightening gas introducing space portion 719 having straightening gas supply ports 1 and supply the straightening gas into the straightening gas introducing space portion 719. In this case, like a straightening gas introducing space portion 719' having a straightening gas supply port 1', the overall area of the outer peripheral surface of the upper portion 1 of the reactor may be enveloped to design the upper portion of the reactor 710 in a dual structure so that the upper portion 1 of the reactor is set as a hollow inner portion and the hollow annular portion is set as the straightening gas introducing space portion. The dual annular structure is preferable because it is simple to manufacture a reactor.

In the vapor deposition apparatus of this aspect of the present invention, the rotational substrate holder 712 is disposed so that the upper surface thereof is located at the lower side of the lower end B of the upper portion 1 of the reactor at a predetermined height difference (H). The height difference H is usually set to be larger than the transition layer thickness of the gas flow supplied to the upper portion of the rotational substrate holder 712, that is, the thickness (T) of the gas layer which is formed by the gas flow of raw-material gas, etc. supplied through the straightening vane 717 as indicated by arrows of FIG. 7, the gas flow having a vector directing from the center to the outer peripheral side portion above the rotational substrate holder 712. If the height difference H is less than the transition layer thickness T, the gas flow directing from the center to the outer peripheral portion of the wafer substrate 711 on the rotational substrate holder 712 is disturbed by the lower end B of the upper portion 1 of the reactor, and the upward blow-up phenomenon of the gas flow along the inner wall of the reactor occurs to promote occurrence of gas eddy flow, so that the amount of deposits on the link portion 718 and the inner wall of the lower portion 2 of the reactor is increased. Further, it is preferable that the upper surface of the rotational substrate holder 712 is on the same horizontal plane as the link portion 718 between the upper portion 1 and the lower portion 2 of the reactor.

The transition layer thickness T of the gas flow above the rotational substrate holder 712 is varied in accordance with the type of the atmospheric gas in the reactor, the inner pressure in the reactor and the rotational number of the rotational substrate holder in a general conventional reactor, and it can be calculated from the following equation (1). The equation (1) is generally introduced on the basis of hydrodynamics:

$$T = 3.22(v/\omega)^{1/2} \quad (1)$$

(v represents coefficient of kinematic viscosity (mm²/s), ω represents an angular velocity of rotation (rad/s)). In this case, the minimum value in the thin film forming process of the vapor deposition apparatus is used as ω . For example, when silane gas is used as the raw-material gas, hydrogen gas is used as the carrier gas and the rotational number of the rotational substrate holder is set to 500 to 2000 rpm (52 to 209 rad/s), the transition layer thickness T is equal to about 5 to 50 mm. Accordingly, it is preferable that the rotational substrate holder is located so that the upper surface thereof is located at a position lower than the lower end B of the small-diameter upper portion 1 of the reactor by a height

difference H which is larger than the T value, whereby the gas stream from the center to the outer periphery above the wafer substrate is further smoothed, and there occurs no adhesion of particles of thin-film forming raw material, so that a uniform thin-film formed wafer having no crystal defect can be formed.

In the reactor having the upper and lower portions which are different in diameter as described above, it is preferable that the small diameter D_1 of the upper portion 1 of the reactor, the large diameter D_2 of the lower portion 2 and the diameter D_s of the rotational substrate holder 12 have the following relationship. For example, D_1 is larger than the diameter of the wafer, and (1) D_2/D_1 is equal to 1.2 or more ($D_2/D_1 \geq 1.2$). If D_1 is smaller than the diameter of the wafer, the particles which fall down from the inner wall surface of the upper portion 1 of the reactor are liable to adhere to the wafer substrate mounted on the rotational substrate holder 712, so that there is such a trend that crystal defects measured as LPD (wafer surface laser scatterer) increase. Further, it is difficult to perform a contactless temperature measurement based on infrared ray on the outer peripheral portion of the wafer substrate which is usually performed in the vapor deposition process. On the other hand, if D_2/D_1 is less than 1.2, the blow-up phenomenon of the ascending gas flow along the wall of the reactor occurs, and thus the gas eddy flow occurs. Accordingly,

(2) The D_1/D_s ratio is equal to 0.7 to 1.2 ($0.7 \leq D_1/D_s \leq 1.2$). If D_1/D_s is smaller than 0.7, the side surface of the upper portion 1 is excessively proximate to the wafer substrate mounted on the rotational substrate holder 712, and the particles which fall down from the inner wall surface of the reactor are liable to adhere to the wafer substrate. Therefore, as in the case where D_1 is smaller than the diameter of the wafer substrate, the crystal defects measured as LPD are increased, and the quality of the thin-film formed wafer substrate is reduced. On the other hand, if D_1/D_s is larger than 1.2, as in the case where the ratio D_2/D_1 is less than 1.2, the blow-up phenomenon of the gas flow along the inner wall of the reactor occurs, and the gas eddy flow occurs.

(3) D_2/D_s is equal to 1.2 or more ($D_2/D_s \geq 1.2$). If D_2/D_s is smaller than 1.2, the gas flow disturbance at the outside of the rotational substrate holder 712 cannot be suppressed. Therefore, the particles adhere to the inner wall of the reactor which corresponds to the outside of the rotational substrate holder 712, and the non-reacted gas is reacted at the lower side of the rotational substrate holder 712, so that the thin-film forming composites deposit on the inner wall of the lower portion 2 of the reactor.

The reactor of the vapor deposition apparatus of the second aspect of the present invention can be designed and manufactured in substantially the same construction as the hollow cylindrical reactor having the same diameter of the conventional vapor deposition apparatus, except that the reactor is a hollow cylindrical reactor sectioned into cylindrical upper and lower portions which are difference in diameter, but continuous with each other, the straightening gas hole is provided to the link portion between the upper and lower portions and each member is disposed at a predetermined position as described above. Further, the vapor deposition method using the vapor deposition apparatus of this aspect of the present invention can be performed in the same manner as described above.

In the vapor deposition apparatus of the present invention thus constructed, the inside of the reactor 710 is evacuated by the exhausting control device which is connected to the exhaust ports 715, and the inner pressure of the reactor is

adjusted to 20 to 50 torr by the reaction gas containing the raw-material gas and the carrier gas. Further, the rotational substrate holder 712 is rotated through the rotational shaft 713 by actuating the motor, and the wafer substrate 711 is also simultaneously rotated. At the same time, the wafer substrate 711 on the rotational substrate holder 712 is heated to about 900 to 1200 degrees Celsius by the heater 714. Further, at the same time, the reaction gas containing the raw-material gas and the carrier gas is supplied from the plural reaction gas supply ports 716 into the reactor 710 while controlling the flow amount of the reaction gas to a predetermined value. The gas flow which is supplied from the plural reaction gas supply ports 716 into the space area S is uniformed in momentum and pressure distribution, and then passed through the holes 717a of the straightening vane 717 to make uniform the gas flow distribution in the reactor and then supplied onto the wafers substrate to uniformly form a thin film on the substrate by vapor deposition. In the vapor deposition apparatus of this aspect of the present invention, simultaneously with the supply of the reaction gas, the same gas as the carrier gas is usually introduced as the straightening gas from the straightening gas flow-out ports 718a of the link portion 718.

In this case, it is preferable that the ratio (G_1/G_C) of the flow rate (G_C) of the reaction gas supplied from the reaction gas supply ports 716 and the flow rate (G_1) of the straightening gas introduced from the straightening gas flow-out holes of the link portion 718 is equal to 0.05 to 2 ($0.05 \leq G_1/G_C \leq 2$). If G_1/G_C is less than 0.05, the gas flow disturbance occurs at the large-diameter portion of the lower portion of the reactor which is located at the outside of the rotational substrate holder 712, and thus this condition is inconvenient. Further, if G_1/G_C is over 2, the gas flow rate at the large-diameter portion at the outside of the rotational substrate holder 712 is excessively high, and the smooth gas flow directing from the center of the rotational substrate holder 712 to the outer periphery thereof above the rotational substrate holder 712 is disturbed, so that any homogeneous thin film having a uniform thickness cannot be grown. Therefore, this condition is inconvenient. Accordingly, by flowing the straightening gas from the straightening gas flow-out holes 718a of the link portion 718 so that the ratio G_1/G_C is within the above range, the flow of the reaction gas on the rotational substrate holder and the flow of the non-reacted gas from the outer peripheral side of the rotational substrate holder to the hollow space at the lower portion of the reactor can be smoothened with no occurrence of gas eddy flow and no occurrence of gas flow disturbance, so that a high-quality homogeneous thin-film formed wafer substrate having little crystal defect can be obtained.

The straightening gas holes provided to the link portion are arranged so as to prevent occurrence of gas eddy flow due to the blow-up of the ascending gas and occurrence of gas flow disturbance at the large-diameter portion of the reactor. The arrangement of the straightening gas holes is not limited to a specific one, and it may be suitably selected in accordance with the reaction conditions such as the capacity of the reactor, the type of the reaction gas, the flow rate of the reaction gas, the rotational speed of the rotational substrate holder, etc. Usually, the flow-out holes having the same diameter are arranged uniformly (at equal intervals) over the whole area of the link portion 718 so that the gas flow rate is uniformly distributed like the stream of the straightening gas as indicated by arrows of FIG. 7. In order to provide a gradient to the flow-out rate distribution of the straightening gas, the straightening gas flow-out holes may

be arranged so that the opening diameter of the straightening gas flow-out holes may be varied so as to have a predetermined opening diameter distribution. For example, in a diagram showing another embodiment of the vapor deposition apparatus of FIG. 8, the straightening gas is made flow from the link portion to have such a gradient flow rate distribution that the flow rate of the straightening gas is higher at the inner peripheral wall side of the lower portion 2 of the reactor and lower at the center side as indicated by arrows which show the stream of the straightening gas from the straightening gas flow-out holes 828a of the link portion 828. In FIG. 8, the same members as those of the apparatus of FIG. 7 are represented by setting the first digit to the same value or by the same reference numerals.

In order to provide the straightening gas flow with such a gradient that the flow rate is gradually increased in the direction from the inner peripheral wall side to the center side, the straightening gas flow-out holes 828a are arranged as shown in a plan view of the link portion 828 of FIG. 9. That is, a larger number of flow-out holes are arranged at the inner peripheral wall side while a smaller number of flow-out holes are arranged at the center side. Such an arrangement of the straightening gas flow-out holes that the straightening gas has a predetermined flow-rate gradient is effective to prevent the occurrence of gas eddy flow and gas flow disturbance, and straighten (rectify) the flow of the reaction gas, so that the non-reacted gas can be smoothly exhausted from the lower portion of the reactor.

In the apparatus of this aspect of the present invention, no restriction is imposed on the flow-out direction of the straightening gas. Usually, the straightening gas is made to flow out in the vertical direction to the surface of the rotational substrate holder as shown in FIGS. 7 and 8. However, if necessary, it may be made to flow out in a direction other than the vertical direction. That is, by forming the straightening gas flow-out holes in the link portion so that the direction of the flow-out holes is not in parallel to the rotational shaft of the rotational substrate holder (i.e., in the vertical direction), but slant at an angle, the straightening gas may be made to flow out from the straightening gas flow-out holes at a slant angle to the rotational shaft of the rotational substrate holder. For example, FIG. 10 is a partially enlarged sectional view showing an example of the link portion area. In FIG. 10, straightening gas flow-out holes 1048a of a link portion 1048 are formed in a slant direction at a predetermined angle toward the inner peripheral wall of the reactor. The straightening gas from the straightening gas flow-out holes 1048a flows out so as to be away from the rotational shaft in the inner peripheral wall direction. The structure of the straightening gas flow-out holes as described above is preferable to prevent occurrence of the gas flow disturbance in the vicinity of the rotator. In this case, the slant angle is usually set to about 10 to 80 degrees to the rotational shaft of the rotational substrate holder so that the straightening gas flow-out holes are slanted toward the inner peripheral wall of the reactor. When the holes are slanted to the direction of the rotational shaft, the straightening gas promotes disturbance of the gas flow which is swept out from the rotator, and thus this is unfavorable.

Further, the straightening gas may be made to flow out in coincidence with the rotational direction of the rotational substrate holder. For example, FIG. 11 is a partially notched perspective view showing an annular link portion 1158 in which straightening gas flow-out holes 1158a are formed obliquely at a predetermined angle in the peripheral direction. In FIG. 11, each straightening gas flow-out hole 1158a is formed so as to extend obliquely in the peripheral direc-

tion from the opening 1158x thereof on the gas flow-in face to the opening 1158y thereof on the gas flow-out face corresponding to the back surface of the annular link portion. The straightening gas from the straightening gas flow-out holes 1158a flows out in the same peripheral direction as the rotation of the rotational substrate holder. The structure of the straightening gas flow-out holes as described above is favorable to prevent the gas flow disturbance in the vicinity of the rotator. In this case, the slant angle is set to about 10 to 80 degrees in the peripheral direction to the gas flow-in face of the link portion. Further, each straightening gas flow-out hole may be slanted not only in the peripheral direction, but also in the radial direction toward the center to flow out the straightening gas in the rotational direction of the rotational substrate holder.

FIG. 12 is a plan view showing an example of a link portion in which straightening gas flow-out holes 1268a of an annular link portion 1268 is formed at a slant angle in the peripheral direction and in the radial direction to the center side. In FIG. 12, the straightening gas flow out hole is formed so as to extend from the opening 1268 thereof on the gas flow-in face 1268 obliquely in the peripheral direction and in the radial direction to the center of the annular link portion and finally intercommunicate with the opening 1268y on the gas flow-out face which corresponds to the back surface. The straightening gas from the straightening gas flow-out hole 1268a flows out as if it rotates in the same rotational direction as the rotational substrate holder. The structure of the straightening gas flow-out holes as described above is favorable because it does not disturb the gas flow in the vicinity of the rotator. In this case, the slant angle is usually set to about 10 to 80 degrees to the gas flow-in face of the link portion, and also to about 10 to 80 degrees in the peripheral direction.

In the vapor deposition apparatus of the first aspect of the present invention, the gas flow rate of the reaction gas flow introduced into the reactor is varied between the center portion and the outer peripheral portion of the reactor, and particularly the gas flow rate at the outer peripheral portion is set to be higher than that at the center portion. Further, in the vapor deposition apparatus of the second aspect of the present invention, the reactor is divided into the small-diameter upper portion and the large-diameter lower portion, and the lower end of the upper portion and the upper end of the lower portion are linked to each other to make continuous the hollow inner spaces of the upper and lower portions. Further, gas flow-out holes are provided to the link portion between the upper and lower portions, and the straightening gas is introduced together with the reaction gas. In both the vapor deposition apparatuses, the upward blow-up phenomenon of the reaction gas in the reactor can be prevented, and thus the increase of the temperature of the reaction gas can be also suppressed. Therefore, the uniform nucleus formation of the raw-material gas can be suppressed, and the particles occurring in vapor phase can be reduced.

According to the particles which adhere to the inner wall of the reactor to shorten the maintenance cycle or directly adhere to the wafer to induce crystal defects can be reduced, so that a high-quality wafer substrate can be manufactured.

Particularly in the vapor deposition apparatus of the first aspect of the present invention, the gas flow in the reactor is kept stabilized and made to smoothly flow through the reactor without producing any particle, any eddy flow and any drift, so that the reaction gas can flow smoothly and with no trap along the wafer substrate on which the thin film is formed. Therefore, no re-doping of dopant occurs and the in-plane resistance of the wafer substrate thus obtained is

further uniformed. Further, in the vapor deposition apparatus of the second aspect of the present invention, the gas flow-out holes are provided to the link portion between the upper and lower portions, and the straightening gas is made to flow simultaneously with the reaction gas, so that the gas flow to the exhaust ports at the lower portion of the reactor is stabilized to be straightened (rectified). Therefore, occurrence of gas eddy flow above the rotational substrate holder can be prevented, the disturbance of the reaction gas flow at the outer peripheral side can be prevented, and the deposition of deposits at the lower portion of the reactor can be prevented by the link portion, so that the maintenance cycle of the reactor can be kept long.

EXAMPLES

Examples 1 to 3

A thin film was formed on a wafer substrate by using a vapor deposition apparatus using a reactor having a circular section which was designed in the same construction as the hollow reactor shown in FIG. 1A. The boundary between the X area and the Z area was set so that the ratio (X/Y) between the interval width X of the outer area (X area) having a larger opening degree from the inner wall of the reactor and the difference Y between the radius (R_p) of the straightening vane 17 and the radius of the rotational substrate holder 12, that is, the radius (R_p) of the orthogonal projection shape of the rotational substrate holder 12 onto the straightening vane 17 was set to the ratio (X/Y) shown in table 1. Gas holes were formed in the straightening vane so that gas holes 17a having a diameter and an opening degree (%) shown in the table 1 were formed in the Z area while gas holes 17b having a diameter and an opening degree (%) shown in the table 1 were formed in the X area, and the straightening vane thus constructed was disposed in the reactor. SiH_4 gas was used as raw-material gas and H_2 gas was used as carrier gas. Further, H_2 gas containing 0.1 ppm of diborane (B_2H_6) was used as dopant. The flow amount (rate) of the reaction gas was adjusted so that the flow rate (V_z) of the reaction gas in the X area and the flow rate (V_z) in the Z area satisfied the ratio (V_x/V_z) shown in the table 1. Further, the reaction temperature, the reaction pressure and the rotational number of the rotational substrate holder were set as shown in the table 1.

Under the vapor deposition condition shown in the table 1, a B_2H_6 -doped silicon thin film was formed on a silicon wafer by vapor deposition. After the vapor deposition of the thin film, adhesion of particles onto the inner wall of the reactor of the vapor deposition apparatus was visually observed, and the adherence condition (large or small) is shown in the table 1. Further, with respect to the characteristics of the crystal phase on the surface of the thin-film formed wafers substrate, the number of LPDs above 0.135 μm or more was measured by using Surfscan 6200 produced by Tencol company, and the measurement result is shown as "number per wafer" in FIG. 1A. Further, the film thickness of the thin film thus formed was measured by an infrared interferometer to measure the maximum thickness (Fmax) and the minimum thickness (Fmin) and then estimate the uniformity of the thin film thickness from $(F_{\text{max}}-F_{\text{min}})/(F_{\text{max}}+F_{\text{min}})\times 100$. The estimation result is shown in the table 1. Further, the resistance value of the thin-film formed wafer substrate thus obtained was measured by the CV method to calculate the maximum value (Rmax) and the minimum value (Rmin) and estimate the uniformity of the resistance value due to the doping of the dopant from $(R_{\text{max}}-R_{\text{min}})/(R_{\text{max}}+R_{\text{min}})\times 100$. The estimation result is shown in the table 1.

Example 4

A thin film was formed on a wafer substrate by using the vapor deposition apparatus having the circular section which was designed in the same construction as the hollow reactor shown in FIG. 4. The straightening vane 17 having an opening degree shown in the table 2 in the overall area thereof was used. Further, a partition plate 18 having the same diameter as the rotational substrate holder was disposed at the circular outer edge portion in the space area above the straightening vane to divide the space area at the upper portion into an Sx area and an Sz area. The reaction gas similar to that of the embodiment 1 was supplied into the Sz area under the condition shown in the table 2, and H₂ gas was supplied into the Sx area at the flow amount (rate) shown in the table 2 to form a B₂H₆-doped silicon thin film on a silicon wafer by vapor deposition. The observation result of the inside of the reactor and the measurement result of the thin-film formed wafer substrate which was obtained by the same measurement as the embodiment 1 are shown in the table 2.

Examples 5 and 6

A thin film was formed on a wafer substrate by using the vapor deposition apparatus having the circular section which was designed in the same construction as the hollow reactor shown in FIGS. 5 (embodiment 5) and FIG. 6 (embodiment 6). The apparatus was designed under the condition shown in the table 2. In the embodiment 6, the reaction gas and the straightening gas were adjusted and supplied so that the H₂ gas was supplied from the link portion 20 into the Y area at the flow rate shown in the table 2, and the ratio between the flow rate (Vx) of the reaction gas in the X area and the flow rate (Vy) of the reaction gas in the Y area was equal to the ratio (Vx/Vy) shown in the table 2 to form a B₂H₆-doped silicon thin film on a silicon wafer by vapor deposition. The observation result in the reactor and the same measurement result on the thin-film formed wafers substrate as the embodiment 1 are shown in the table 2.

Comparison Examples 1 and 2

A B₂H₆-doped silicon thin film was formed on a silicon wafer in the same manner as the embodiment 1 by using the vapor deposition apparatus which was designed in the same construction as the reactor of the embodiment 1, except that the straightening vane was formed under the condition shown in the table 2 and disposed in the reactor for a comparison example 1 in which the ratio Vx/Vz was set to be less than a predetermined value and a comparison example 2 in which the ratio Vx/Vz is set to more than a predetermined value. The observation result in the reactor and the measurement result on the thin-film formed wafer substrate are shown in the table 3.

Comparison Examples 3 and 4

By using the vapor deposition apparatus using the same reactor as the conventional vapor deposition apparatus shown in FIG. 14 in which the gas holes having a uniform opening degree were uniformly formed, a B₂H₆-doped silicon thin film was formed on the surface of a silicon wafer in the same manner as the embodiment 1 under the vapor deposition reaction condition shown in the table 2. The observation result of the inside of the reactor and the measurement result on the thin-film formed wafer substrate obtained in the same manner are shown in the table 3.

As is apparent from the examples and the comparison examples, when the flow rate of the reaction gas in the X

area having a predetermined width around the inner periphery of the reactor is set to be higher than that in the Z area at the center side by a predetermined rate, the number of LPDs of the crystal phase on the surface of the thin-film formed wafer substrate is equal to 1000 or less, so that an excellent thin-film formed wafer substrate can be obtained. The number of LPDs is reduced to about 1/50 or less as compared with the comparison example 1 in which the flow rate ratio is lower than the predetermined ratio and the comparison example in which the carrier gas was made to flow in the same manner as the embodiment in the conventional system. Further, the number of LPDs is reduced to about 1/30 or less as compared with the comparison example 2 in which the reaction gas was made to flow at a high flow rate in an area broader than the predetermined width. Still further, the number of LPDs in the comparison example 4 in which the carrier gas was made to flow at 200 liter/minute by the conventional system was measured 1000 or more. Therefore, it is apparent that the vapor deposition apparatus and method of the present invention provide more excellent thin films. With respect to the uniformity of the thin film thickness, the uniformity in the present invention was lower than the comparison example 4, however, the uniformity of the resistance value was higher than the comparison example 4. Accordingly, the present invention can provide a higher quality thin-film formed wafer substrate without using a large amount of carrier gas.

Examples 7 to 11

The vapor deposition apparatus used for these examples was designed in a hollow cylinder structure like the reactor shown in FIG. 7, the inner D₁ of the upper portion of the reactor, the inner diameter D₂ of the lower portion of the reactor and the diameter D₃ of the rotational substrate holder were set as shown in table 4, and the lower end B of the upper portion and the upper surface of the rotational substrate holder were located to keep a height difference H shown in the table 4 therebetween. SiH₄ gas was used as raw-material gas, H₂ gas was used as carrier gas, and H₂ gas containing 0.1 ppm diborane (B₂H₆) was used as dopant. These gas were supplied at a flow rate shown in the table 4, and the same type H₂ gas as the carrier gas was vertically and uniformly supplied at a flow rate shown in the table 4 as straightening gas. The ratio (G₁/G_C) between the flow rate of the reaction gas (m/s) and the flow rate of the straightening gas (m/s), the reaction temperature, the reaction pressure and the rotational number of the rotational substrate holder are shown in the table 4.

A B₂H₆-doped silicon thin film was formed on a silicon wafer under the vapor deposition condition shown in the table 4. After the vapor deposition, the adhesion of particles to the link portion and the inner peripheral wall of the lower portion of the reactor in the used vapor deposition apparatus was visually observed to check the adhesion condition (large amount or small amount) of the particles, and the result is shown in the table 4. With respect to the characteristics of the crystal phase on the surface of the thin-film formed wafer substrate thus obtained, the number of LPDs (wafer surface laser scatterers) of 0.135 μ m or more was measured by using Surfscan 6200 produced of Tencol company. The result is shown as "number per wafer" in the table 4. Further, the film thickness of the thin film thus formed was measured by using an infrared interferometer, and the maximum thickness (Fmax) and the minimum thickness (Fmin) were determined to estimate the uniformity of the thin film thickness from (Fmax-Fmin)/(Fmax+Fmin)×100. The estimation result is shown in the table 4. Further, the resistance value of

the thin-film formed wafer substrate thus obtained was measured by the C-V method, and the maximum value (Rmax) and the minimum value (Rmin) were calculated to estimate the uniformity of the resistance value due to the doping of the dopant from $(R_{\max}-R_{\min})/(R_{\max}+R_{\min}) \times 100$. The result is shown in the table 4.

Comparison Examples 5 and 6

The vapor deposition apparatus used for these comparison examples 5 and 6 was designed in the same construction as the reactor of the embodiment 7 except that the straightening gas was made to flow from the link portion at an extremely low flow rate (comparison example 5) or at a high flow rate (comparison example 6), and a B_2H_6 -doped silicon thin film was formed on a silicon wafer in the same manner as the embodiment 7. The observation result in the apparatus and the measurement result on the thin-film formed wafer substrate are shown in the table 5.

Comparison Examples 7 to 17

A silicon thin film was formed on a wafer substrate in the same manner as the embodiment 7 by using a reactor 1370 of the vapor deposition apparatus shown in FIG. 13. In FIG. 13, the vapor deposition apparatus used for these comparison examples was designed in the same construction as the vapor deposition apparatus having the reactor of the embodiment 7, except that the reactor 1370 had a small-diameter upper portion 1' and a large-diameter lower portion 2' which were different in inner diameter, and no straightening gas flow-out port was provided to the link portion between the upper and lower portion. In FIG. 13, the same members as the apparatus of FIG. 7 are represented by setting the same numerals at the lower digits or by the same numerals. In the reactor 1370, the ratio of the inner diameter D_1 of the upper portion of the reactor, the inner diameter D_2 of the lower portion of the reactor and the diameter D_3 of the rotational substrate holder was varied as shown in the tables 5 and 6, and a B_2H_6 -doped silicon thin film was formed on a silicon wafer in the same manner as the embodiment 7. The observation of the inside of the apparatus and the measurement result on the thin-film formed wafer substrate obtained by the same measurement as the embodiment are shown in the tables 5, 6 and 7.

Comparison Examples 18 and 19

A B_2H_6 -doped silicon thin film was formed on the surface of a silicon wafer under the same vapor deposition reaction condition as shown in the table 7 by using a reactor which was designed in the same construction as a reactor 80 of a conventional vapor deposition apparatus shown in FIG. 14 in which the reactor was not divided into upper and lower portions (i.e., the upper and lower portions had the same diameter), and thus no link portion was provided. The observation result of the inside of the apparatus and the measurement result on the thin-film formed wafer substrate are shown in the table 7.

As is apparent from the embodiments and the comparison examples, when the reactor was divided into upper and lower portions which were different in diameter and the straightening gas was made to flow from the link portion at which the diameter of the reactor was increased, the number of LPDs of the crystal phase of the surface of the thin-film formed wafer substrate thus obtained was equal to 100 or less, that is, the number of LPDs was reduced to about $\frac{1}{500}$ or less as compared with the comparison example 18 which used the conventional vapor deposition apparatus under the

same reaction condition. Further, it is apparent that the uniformity of the thin film thickness was equal to 1 or less and thus an extremely uniform thin film was formed. Further, the uniformity of the resistance value was equal to 4.4 or less. That is, there occurred no crystal defect, and the re-doping of the dopant was prevented, so that a homogeneous thin film was formed. Further, when the carrier gas was made to flow at a high flow rate in the conventional apparatus as in the case of the comparison example 19, the film thickness was relatively uniform, the number of LPDs was small and the crystal phase was relatively excellent. However, it was estimated that the uniformity of the resistance value was low and gas flow disturbance occurred at the outer peripheral side of the rotational substrate holder. Further, a large amount of deposits were observed at the lower portion of the reactor, and it could be estimated that the maintenance cycle was shortened.

On the other hand, as in the case of the comparison examples 7 to 17, even in the case where the reactor having the upper and lower portions which were different in diameter was used, if no straightening gas was made to flow from the link portion, the uniformity of the film thickness, the uniformity of the resistance value, the number of LPDs, and the amount of deposits at the lower portion of the reactor were estimated and measured to be more excellent in the comparison example 7 having the same diameter ratio of the upper and lower portions as the embodiments than in the conventional case where the carrier was made to flow at an usual flow rate (comparison example 18), however, these characteristics were more deteriorated as compared with the embodiments in which the straightening gas was made to flow. Further, it is apparent that even when the ratio between the diameter of the lower portion of the reactor and the diameter of the rotational substrate holder was variously varied, the comparison examples cannot provided more excellent results as compared with the embodiments. The comparison examples 12 and 13 in which the diameter of the lower portion was set to about 3 to 4 times of the diameter of the upper portion provided relatively excellent thin films. However, the dimension of the apparatus is excessively large in size. Further, in these cases, deposits were observed at the link portion, and the crystal defects were somewhat increased, resulting in increase of the maintenance cycle of the reactor. Still further, in the comparison example 12 in which the lower end B of the upper portion of the reactor and the upper surface of the rotational substrate holder were proximate to each other at a height interval of 5 mm, the number of LPDs was remarkably increased, and the defect of the crystal phase, the uniformity of the thin film thickness and the uniformity of the resistance value are remarkably deteriorated.

Further, according to the comparison examples 5 and 6, when the reactor of the vapor deposition apparatus of the present invention was used and the flow rate of the straightening gas from the link portion was set to be lower than the flow rate of the reaction gas, the thin film obtained was relatively excellent. However, when the flow rate of the straightening gas was set to three times of the flow rate of the reaction gas, the number of LPDs was remarkably reduced, and the deposition amount at the lower portion of the reactor was increased although no deposits was observed at the link portion. Therefore, the characteristics of the thin film thus obtained were deteriorated.

The transition layer thickness T in the embodiments (examples) and the comparison examples was calculated as 18 to 21 mm by substituting $\omega=209$ rad/s, $v=6608$ to 8811 mm^2/s into the equation (1).

What is claimed is:

1. A vapor deposition apparatus comprising:

a hollow reactor having a gas supply port at a top portion thereof and an exhaust port at a bottom portion thereof, said gas supply port being adapted to supply reaction gas into said reactor to form a thin film on a surface of a wafer substrate;

a rotational substrate holder positioned inside said reactor, said substrate holder being adapted to seat a wafer substrate; and

a straightening vane having a central portion and an outer portion extending radially outwardly from said central portion,

wherein said central portion is defined by an area at least as large as an area of said substrate holder and concentric with said substrate holder, and

wherein said central portion has first gas holes and said outer portion has second gas holes, the total area of the openings of said second gas holes being larger than that of the first gas holes.

2. The vapor deposition apparatus as claimed in claim 1 wherein said straightening vane and said substrate holder each are circular and said reactor has a cylindrical wall, said straightening vane extending to an inner peripheral surface of said reactor cylindrical wall, and wherein said outer portion has a radial distance (X), which is equal to less than a difference (Y) between the radius (R_p) of the reactor cylindrical wall and the radius (R_s) of the substrate holder or an equivalent projected radius (R_p) thereof.

3. The vapor deposition apparatus as claimed in claim 2, wherein a ratio (X/Y) between said radial distance (X) of said outer portion and said difference ($Y=R_p-R_s$ (or R_s)) is set to 0.02 to 1.0.

4. The vapor deposition apparatus as claimed in claim 1, wherein said reactor is designed to be circular in horizontal section, and said straightening vane and said rotational substrate holder are coaxially disposed in said reactor.

5. The vapor deposition apparatus as claimed in claim 1, wherein a space area is defined between the top portion of said reactor and said rotational substrate holder, the space area being divided into at least two sections by a partition member disposed radially outwardly from said rotational substrate holder, and at least two reaction gas supply ports being provided to each of the sections.

6. The vapor deposition apparatus as claimed in claim 5, wherein said straightening vane and said substrate holder each are circular and said reactor has a cylindrical wall, said straightening vane extending to an inner peripheral surface of said reactor cylindrical wall, wherein said outer portion has a radial distance (X), which is equal to less than a difference (Y) between the radius (R_p) of the reactor cylindrical wall and the radius (R_s) of the substrate holder or an equivalent projected radius (R_p) thereof, and wherein a ratio (X/Y) between said radial distance (X) of said outer portion and said difference ($Y=R_p-R_s$ (or R_s)) is set to 0.02 to 1.0.

7. The vapor deposition apparatus as claimed in claim 5, wherein said reactor is designed to be circular in horizontal section, and said straightening vane and said rotational substrate holder are coaxially disposed in said reactor.

8. The vapor deposition apparatus as claimed in claim 6, wherein an individual reaction gas supply system is connected through said reaction gas supply ports to each of said sections.

9. The vapor deposition apparatus as claimed in claim 1, wherein said reactor is divided into upper and lower portions having different inner diameters, the inner diameter of said

upper portion is smaller than the inner diameter of said lower portion, and the lower end of said upper portion and the upper end of said lower portion are connected to each other, forming continuous hollow upper and lower portions.

10. A vapor deposition apparatus comprising:

a hollow reactor having a gas supply port in the upper portion thereof and an exhaust port in the lower portion thereof, said gas supply port being adapted to supply reaction gas into said reactor to form a thin film on a surface of a wafer substrate, said reactor being sectioned into upper and lower portions having different inner diameters, the inner diameter of said upper portion being smaller than the inner diameter of said lower portion;

a link portion connecting the lower end of said upper portion to the upper end of the lower portion, said link portion having straightening gas flow-out holes;

a rotational substrate holder, which is adapted to seat a wafer substrate, positioned inside said reactor below the lower end of said upper portion; and

a straightening vane having a plurality of gas holes situated in the upper portion of the reactor,

wherein said straightening gas flow-out holes are directed either vertically downwardly or downwardly and outwardly toward the lower portion to direct straightening gas away from the substrate holder.

11. The vapor deposition apparatus as claimed in claim 10, wherein a space portion is provided above said link portion so as to hermetically envelop said straightening gas flow-out holes, and straightening gas supply ports are provided in said space portion.

12. The vapor deposition apparatus as claimed in claim 11, wherein said space portion and said upper portion are constructed in a dual-wall structure, and an outside surface of the space portion extends from the upper end of the lower portion through said link portion.

13. The vapor deposition apparatus as claimed in claim 11, wherein the side surface of said upper portion is vertical to the upper surface of said rotational substrate holder.

14. The vapor deposition apparatus as claimed in claim 10, wherein the hollow inside of said reactor is designed to be circular in horizontal section, the diameter of said upper portion (D_1) is larger than the diameter of said wafer substrate, said rotational substrate holder is designed in a circular shape, and the ratio (D_1/D_s) between the diameter of said upper portion (D_1) and the diameter of said rotational substrate holder (D_s) is set to 0.7 to 1.2.

15. The vapor deposition apparatus as claimed in claim 14, wherein the ratio (D_2/D_1) between the diameter of said upper portion (D_1) and the diameter of said lower portion (D_2) is set to 1.2 or more.

16. The vapor deposition apparatus as claimed in claim 15, wherein the ratio (D_2/D_s) between the diameter of said lower portion (D_2) and the diameter of said rotational substrate holder (D_s) is set to 1.2 or more.

17. The vapor deposition apparatus as claimed in claim 14, the ratio (D_2/D_s) between the diameter of said lower portion (D_2) and the diameter of said rotational substrate holder (D_s) is set to 1.2 or more.

18. The vapor deposition apparatus as claimed in claim 10, wherein a transition layer thickness (T) of gas flow above an upper surface of said rotational substrate holder is calculated from $T=3.22(\nu/\omega)^{1/2}$, where ν represents coefficient of kinematic viscosity (mm^2/s) and ω represents an angular velocity of rotation (rad/s).

19. The vapor deposition apparatus as claimed in claim 18, wherein the rotation of said rotational substrate holder is

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controlled so that the transition layer thickness (T) is smaller than a height difference (H) between the lower end of said upper portion and the upper surface of said rotational substrate holder.

20. The vapor deposition apparatus as claimed in claim 10, wherein a part of said link portion and the upper surface of said rotational substrate holder are located on the same horizontal plane.

21. A vapor deposition apparatus comprising:

a hollow reactor having a gas supply port at a top portion thereof and an exhaust port at a bottom portion thereof, the gas supply port being adapted to supply reaction gas into the reactor to form a thin film on a surface of a wafer substrate;

a rotational substrate holder positioned inside the reactor, the substrate holder being adapted to seat a wafer substrate; and

a straightening vane having a central portion and an outer portion extending radially outwardly from the central portion, wherein a space area is defined between the top portion of the reactor and the rotational substrate holder, the space area being divided into at least two sections by a partition member disposed radially outwardly from the rotational substrate holder, at least two reaction gas supply ports being provided to each of the sections.

22. The vapor deposition apparatus as claimed in claim 4, wherein the reactor is designed to be circular in horizontal section, and the straightening vane and the rotational substrate holder are coaxially disposed in the reactor.

23. The vapor deposition apparatus as claimed in claim 21, wherein an individual reaction gas supply system is connected through the reaction gas supply ports to each of the sections.

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24. A vapor deposition apparatus comprising:

a hollow reactor having a gas supply port in the upper portion thereof and an exhaust port in the lower portion thereof, the gas supply port being adapted to supply reaction gas into the reactor to form a thin film on a surface of a wafer substrate, the reactor being sectioned into upper and lower portions having different inner diameters, the inner diameter of the upper portion being smaller than the inner diameter of the lower portion;

a link portion connecting the lower end of the upper portion to the upper end of the lower portion, the link portion having straightening gas flow-out holes;

a rotational substrate holder, which is adapted to seat a wafer substrate, positioned inside the reactor below the lower end of the upper portion; and

a straightening vane having a plurality of gas holes situated in the upper portion of the reactor,

wherein a space portion is provided above the link portion so as to hermetically envelop the straightening gas flow-out holes, the space portion being provided with straightening gas supply ports.

25. The vapor deposition apparatus as claimed in claim 24, wherein the space portion and the upper portion are constructed in a dual-wall structure, and an outside surface of the space portion extends from the upper end of the lower portion through the link portion.

* * * * *



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Nomura

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(45) Date of Patent: **Jun. 18, 2002**

(54) **FUEL DISTRIBUTION PIPE IN FUEL INJECTION APPARATUS**

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(73) Assignee: **Keihin Corporation, Tokyo (JP)**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(52) U.S. Cl. **123/456; 123/541; 123/41.31**

(58) Field of Search **123/456, 41.31, 123/541, 514, 468, 469**

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(57) **ABSTRACT**

The invention provides a fuel distribution pipe which can restrict an increase of temperature of a fuel flowing within a fuel distribution path of the fuel distribution pipe, whereby it is possible to improve an operation property of the engine. In the fuel distribution pipe, the fuel distribution path is pierced along a line X—X in a direction of a longitudinal axis of the fuel distribution pipe and an injection valve supporting hole for inserting and supporting a rear end portion of the fuel injection valve and a fuel introduction path for supplying a fuel having a pressure increased by a fuel pump are continuously provided in the fuel distribution path of the fuel distribution pipe, and a cooling water flow path extending along the line X—X in the direction of the longitudinal axis of the fuel distribution path and sectioned from the fuel distribution path is provided on an outer periphery of the fuel distribution path, thereby introducing a cooling water into the cooling water flow path.

9 Claims, 10 Drawing Sheets

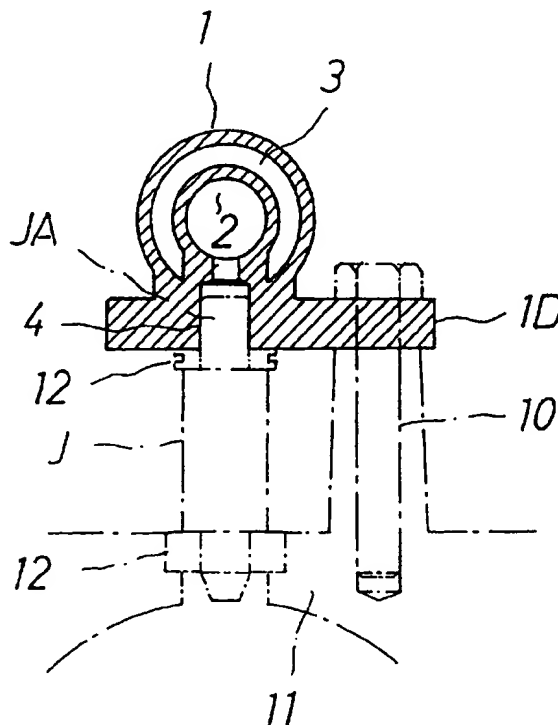


FIG. 1

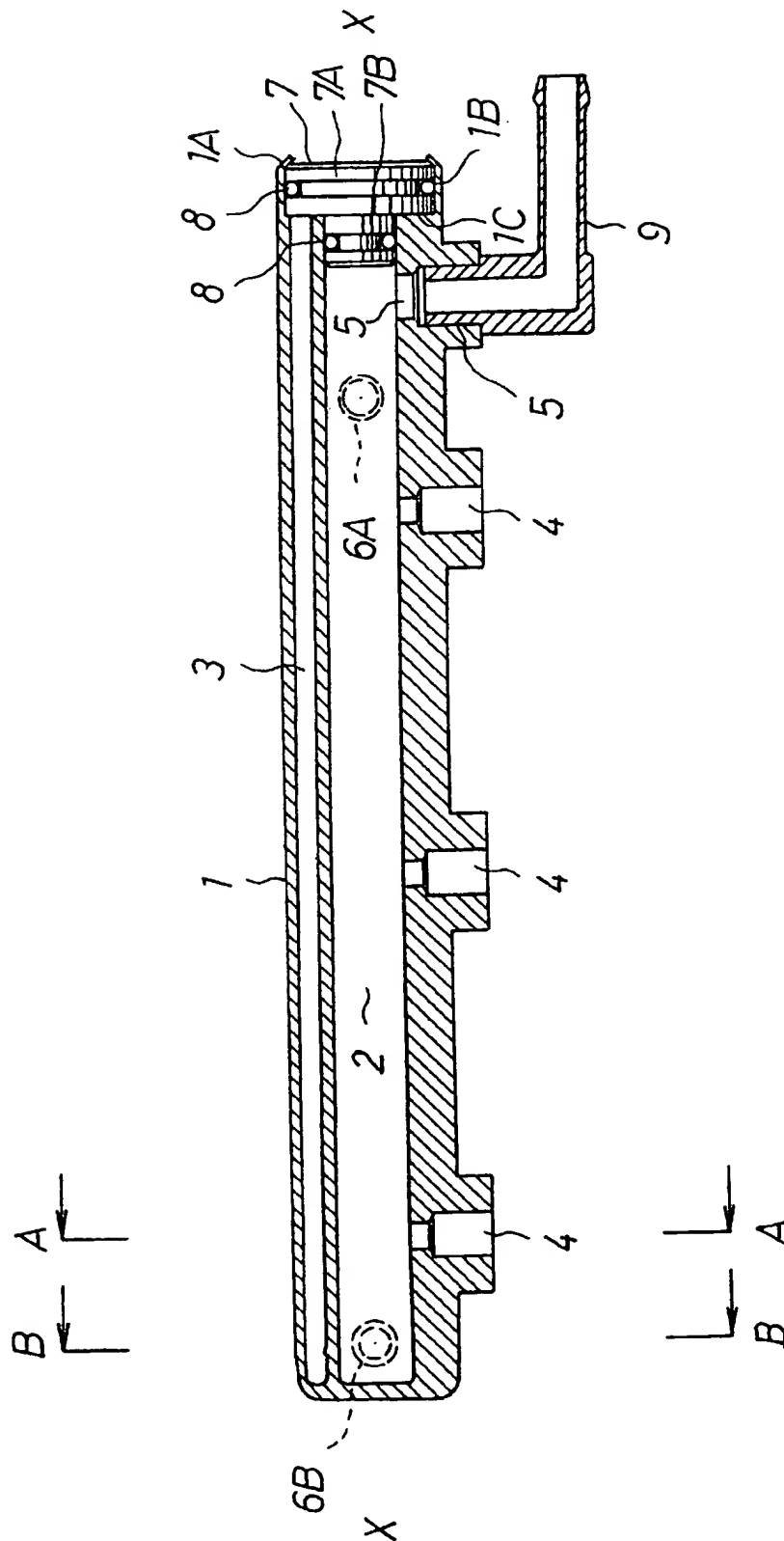


FIG. 2

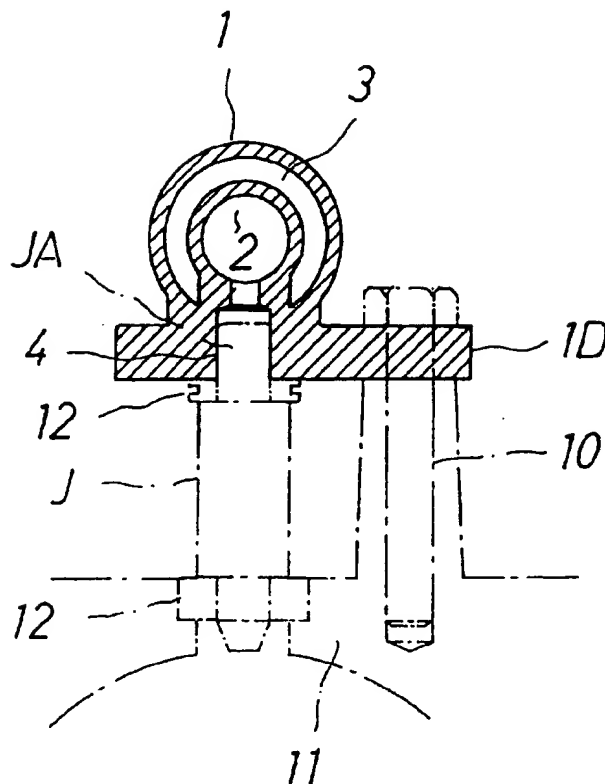


FIG. 3

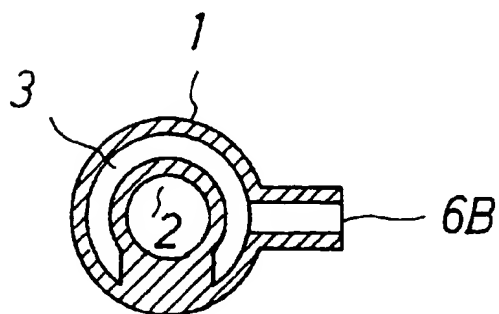


FIG. 4

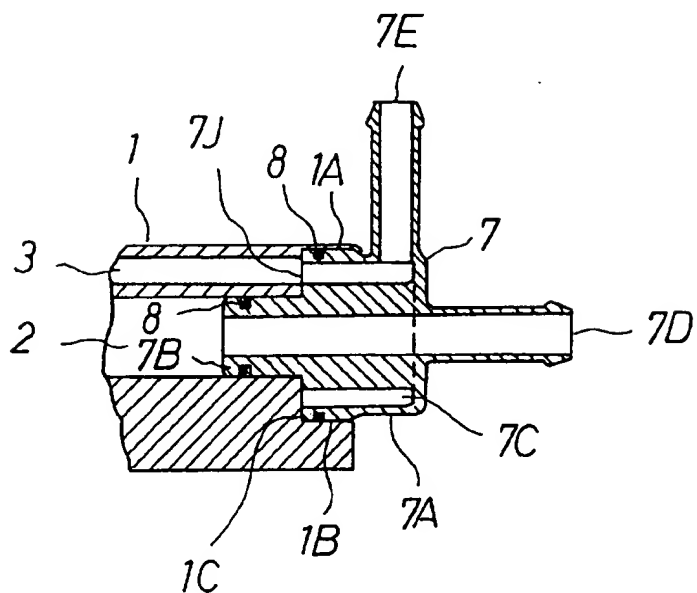


FIG. 5

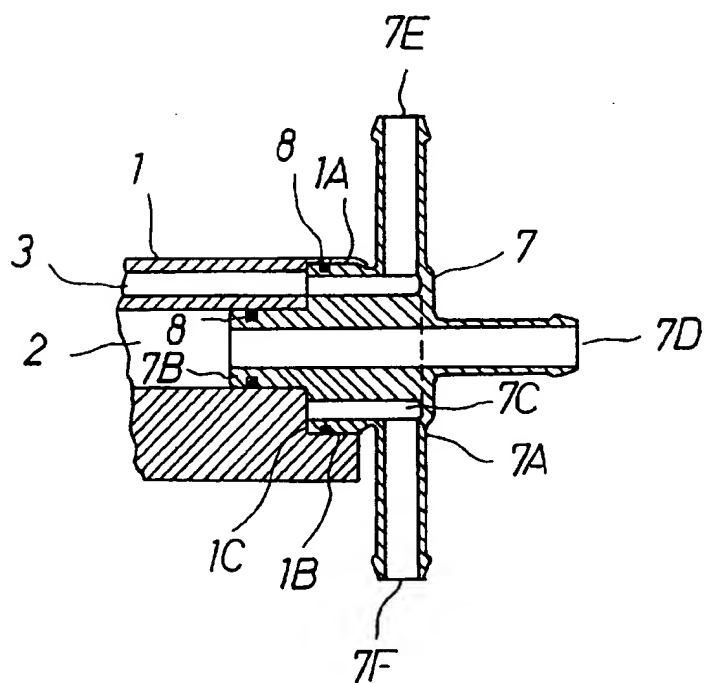


FIG. 6

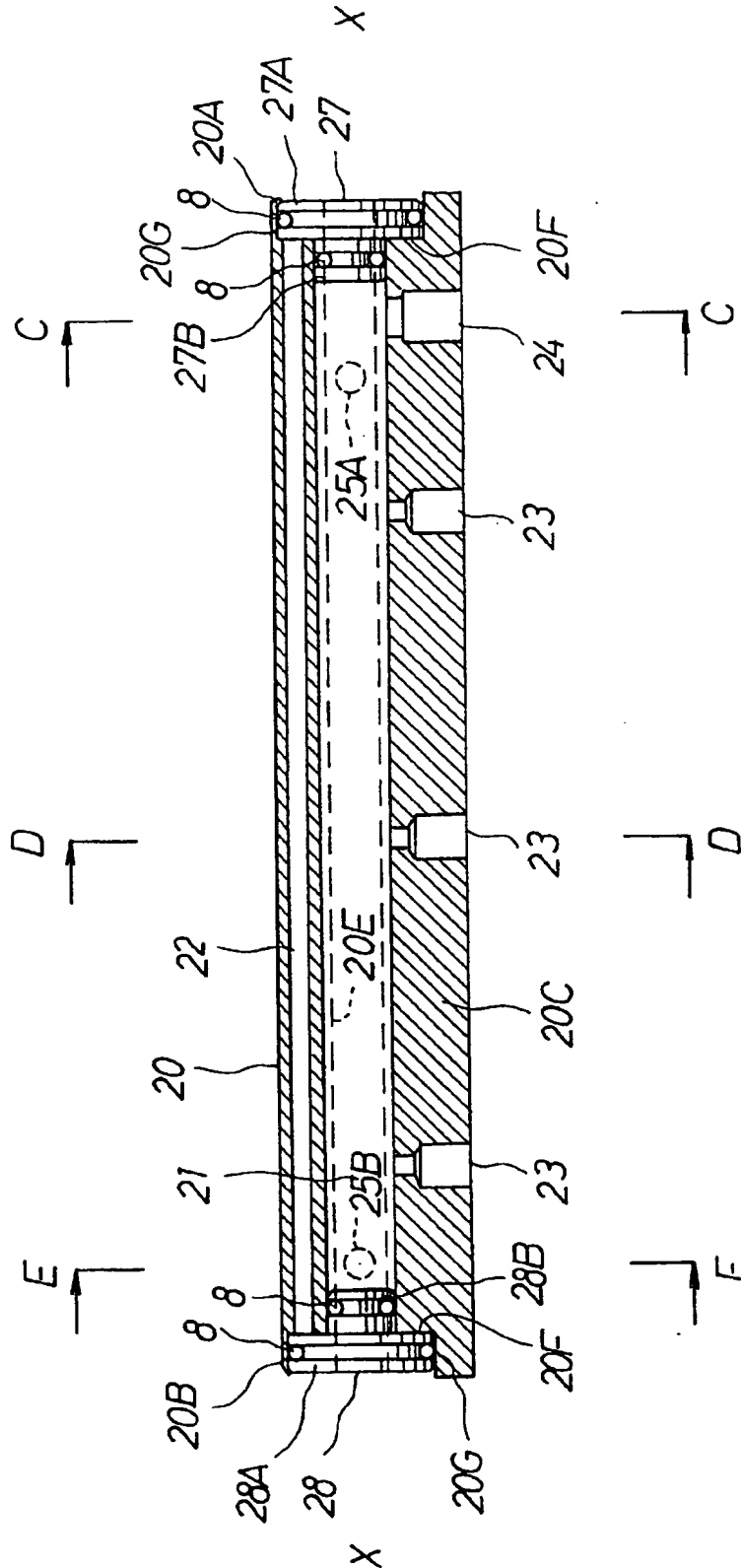


FIG. 7

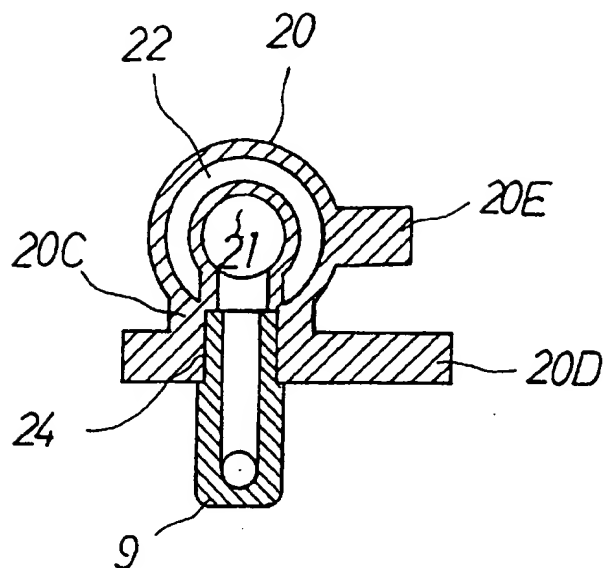


FIG. 8

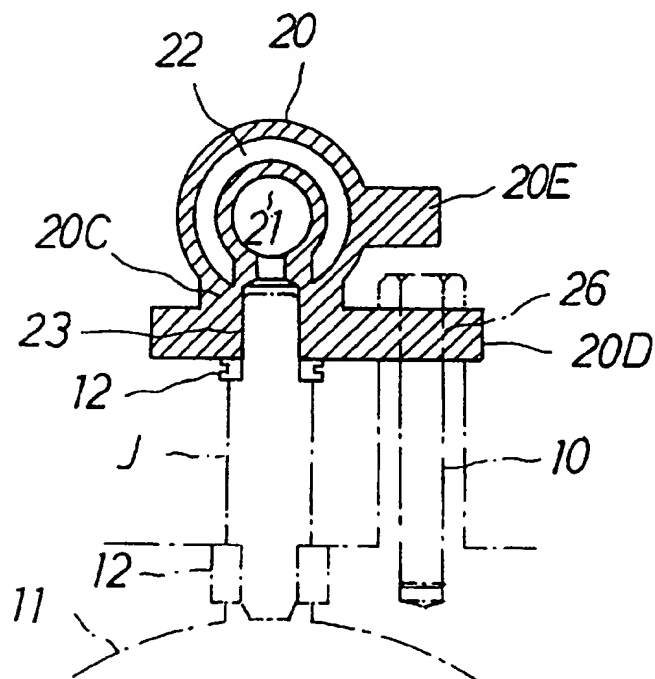


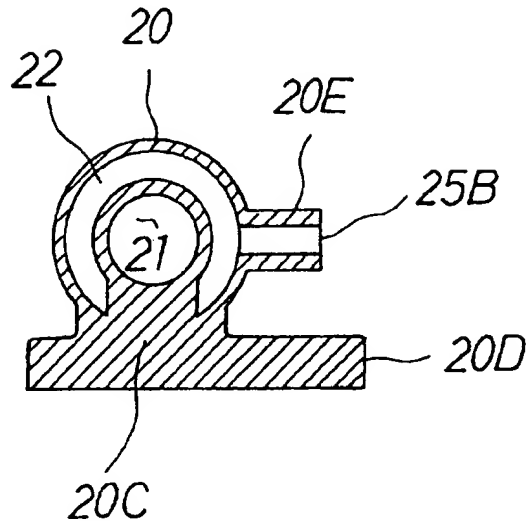
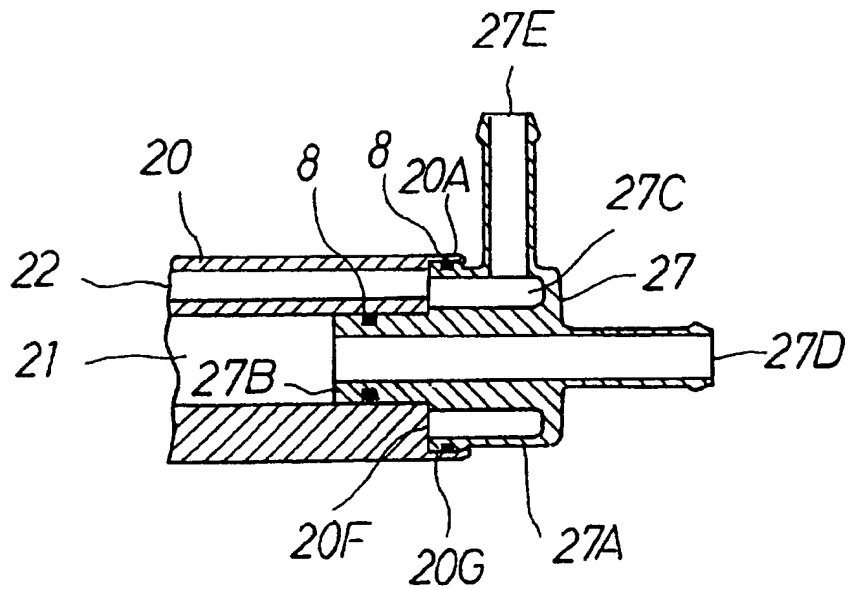
FIG. 9**FIG. 10**

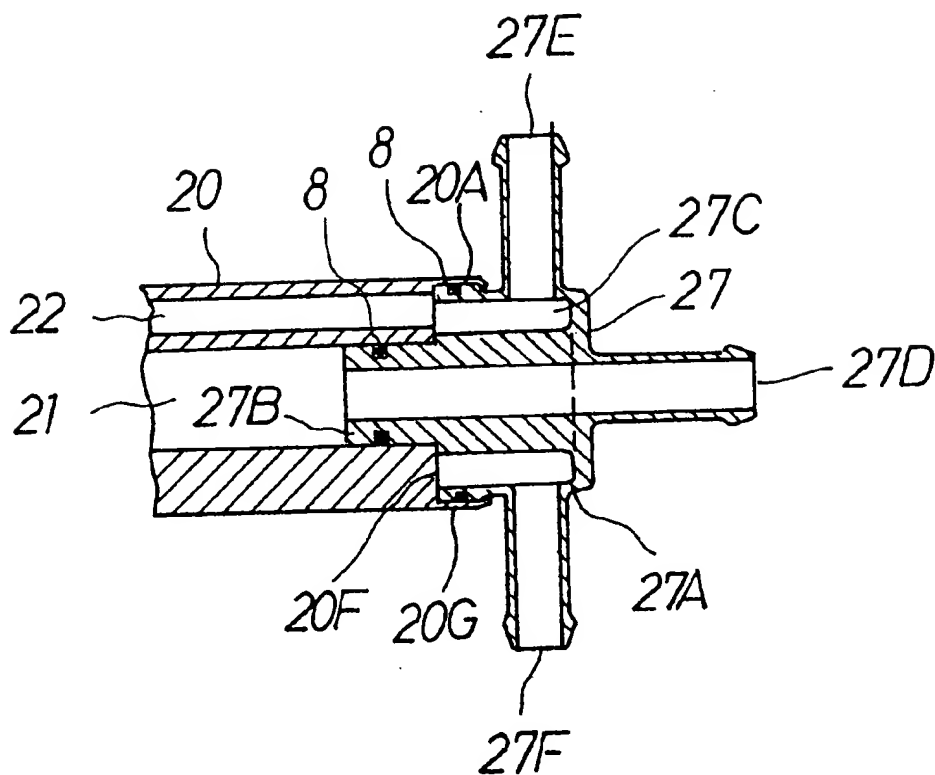
FIG. 11

FIG. 12

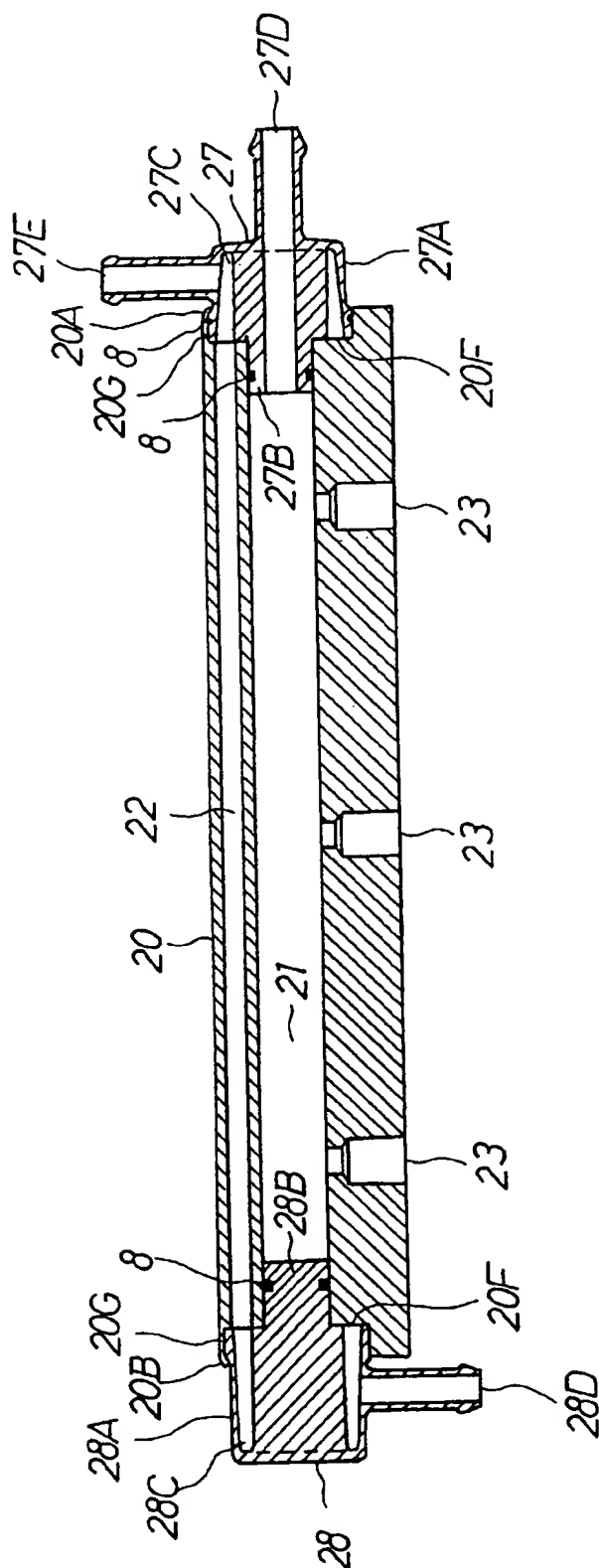


FIG. 13

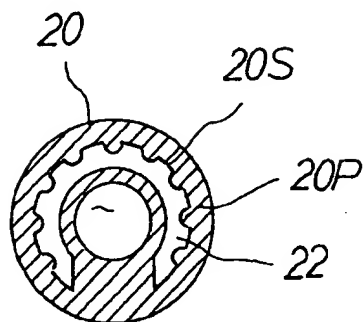


FIG. 14

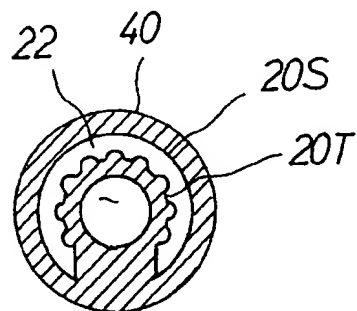


FIG. 15

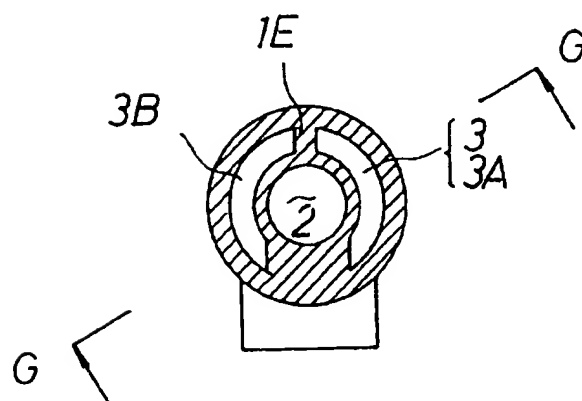
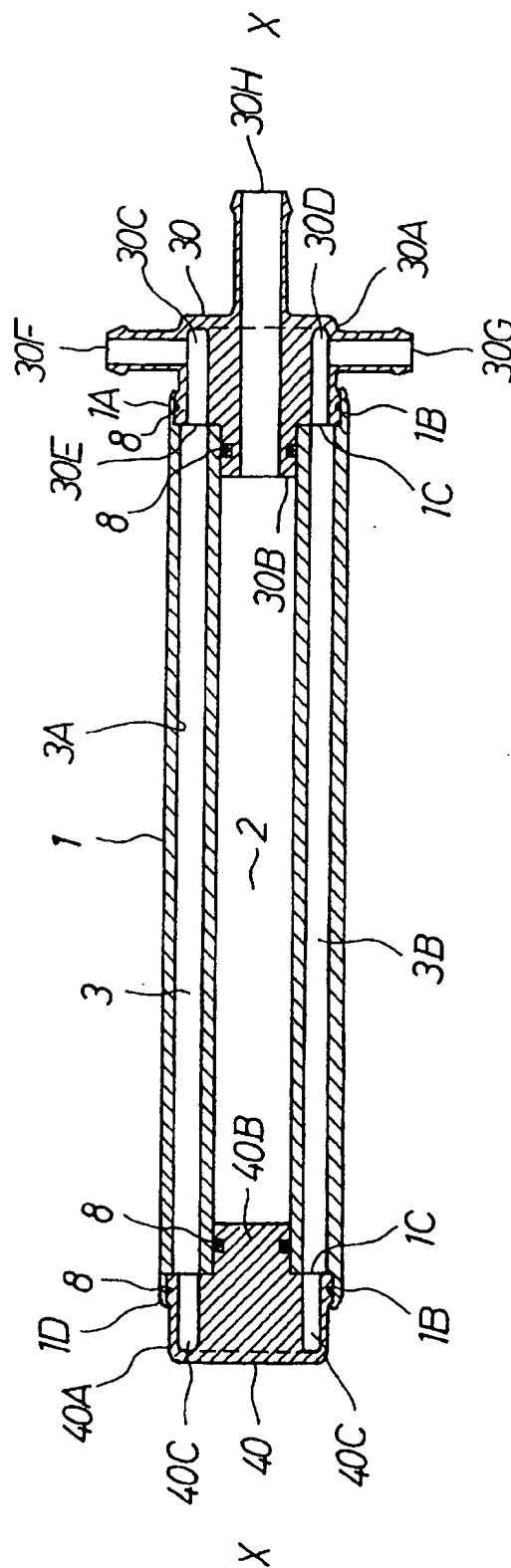


FIG. 16



FUEL DISTRIBUTION PIPE IN FUEL INJECTION APPARATUS

BACKGROUND OF THE INVENTION

1. Technical Field

The present invention relates to a fuel injection apparatus which increases a pressure of a fuel within a fuel source by a fuel pump so as to supply the fuel into the fuel distribution path of a fuel distribution pipe and injects and supplies a fuel controlled by a fuel injection valve mounted to the fuel distribution pipe toward an engine, and more particularly to a fuel distribution pipe provided with a fuel distribution path.

2. Description of the Prior Art

A fuel distribution path is pierced in a fuel distribution pipe in a longitudinal axial direction.

A fuel introduction path is connected and opened to the fuel distribution path, an injection valve supporting hole is opened to the fuel distribution path, a pressure of a fuel within a fuel source is increased and the fuel is supplied to the fuel introduction path by a fuel pump, and a rear end portion of a fuel injection valve for injecting and supplying the fuel is pressed into and supported to the injection valve supporting hole. Accordingly, the pressure of the fuel within the fuel source is increased by the fuel pump, and the fuel having the increased pressure is supplied into the fuel distribution path of the fuel distribution pipe via the fuel introduction path.

On the other hand, the fuel injection valve is structured such as to perform a fuel injection on the basis of an injection signal output from an electronic control unit (ECU), and the fuel having the increased pressure within the fuel distribution path is injected to an engine or an intake pipe or the like connected to the engine via the fuel injection valve.

In accordance with the conventional fuel injection apparatus mentioned above, a temperature of the fuel within the fuel distribution path of the fuel distribution pipe tends to be increased, and this is caused by the following reasons.

Firstly, it is because the fuel introduction path connecting the fuel pump to the fuel distribution path is heated and the fuel having an increased temperature is easily supplied into the fuel distribution path.

That is, the fuel introduction path is structured such as to be piped around within an engine room in which an atmospheric temperature is largely increased, whereby the fuel introduction path is heated by a heat within the engine room and the fuel flowing therein is heated so as to increase the temperature thereof.

Secondly, it is because the fuel distribution pipe is directly heated.

That is, the fuel distribution pipe is structured such as to be disposed within the engine room and arranged significantly near the engine, whereby the temperature is easily increased particularly due to an influence of heat generated at a time of operating the engine, so that the fuel within the fuel distribution pipe is directly heated.

Accordingly, when the temperature of the fuel within the fuel distribution path of the fuel distribution pipe is increased due to the causes mentioned above, vapors are generated in the fuel flowing within the fuel distribution path, so that when the vapors are supplied to the engine in a state of being contained in the fuel injected from the fuel injection valve, there is a risk of damaging a good operation property of the engine.

That is, when the fuel containing the vapors is supplied, the fuel is intermittently supplied and the fuel can not be continuously and stably supplied. Further, since an amount of fuel actually supplied is reduced in correspondence to an amount of the vapors, it is impossible to stably and accurately supply the fuel.

SUMMARY OF THE INVENTION

The present invention is made by taking the problems mentioned above into consideration, and a first object of the present invention is to provide a fuel distribution pipe which can restrict an increase of temperature of a fuel flowing within a fuel distribution path of a fuel distribution pipe so as to continuously supply the fuel stably and accurately to an engine, whereby it is possible to improve an operation property of the engine.

Further, a second object of the present invention is to prevent a sound caused by a pressure change of a fuel within a fuel distribution path generated by an opening and closing operation of a fuel injection valve from being transmitted to the outside.

In order to achieve the objects mentioned above, in accordance with a first aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus structured such as to increase a pressure of a fuel within a fuel source by a fuel pump so as to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel injection valve attached to the fuel distribution pipe, in which the fuel distribution path is pierced along a line X—X in a direction of a longitudinal of the fuel distribution pipe and an injection valve supporting hole for inserting and supporting a rear end portion of the fuel injection valve and a fuel introduction path for supplying a fuel having a pressure increased by a fuel pump are continuously provided in the fuel distribution path of the fuel distribution pipe, and in which a cooling water flow path extending along the line X—X in the direction of the longitudinal axis of the fuel distribution path and sectioned from the fuel distribution path is provided on an outer periphery of the fuel distribution path, thereby introducing a cooling water into the cooling water flow path.

Further, in accordance with a second aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus as recited in the first aspect, wherein a cooling water introduction path and a cooling water discharge path are opened to the cooling water flow path, thereby circulating the cooling water within the cooling water flow path.

Further, in accordance with a third aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus as recited in the first aspect, wherein the fuel distribution path and the cooling water flow path are formed within the fuel distribution pipe in a sectional manner by forming the fuel distribution path and the cooling water flow path formed in the fuel distribution pipe so as to be opened in one end portion by a casting process, and closing the one end portion by one side closing member, and the fuel introduction path connected to the fuel distribution path and a cooling water introduction path connected to the cooling water flow path are provided in the one side closing member.

Further, in accordance with a fourth aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus as recited in the third aspect, wherein the fuel introduction path connected to the fuel distribution path, the cooling water introduction path connected to the cooling

water flow path and a cooling water discharge path are provided in the one side closing member.

Further, in accordance with a fifth aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus as recited in the first aspect, wherein the fuel distribution path disposed along the line X—X in the direction of the longitudinal axis within the fuel distribution pipe is formed so as to be sectioned from the cooling water flow path by forming the fuel distribution path and the cooling water flow path in the fuel distribution pipe by a drawing process along the line X—X in the direction of the longitudinal axis and closing the fuel distribution path and the cooling water flow path respectively open to one end portion and another end portion of the fuel distribution pipe by one side closing member and another side closing member.

Further, in accordance with a sixth aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus as recited in the fifth aspect, wherein the fuel introduction path connected to the fuel distribution path and the cooling water introduction path connected to the cooling water flow path are provided in the one side closing member.

Further, in accordance with a seventh aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus as recited in the fifth aspect, wherein the fuel introduction path connected to the fuel distribution path and the cooling water introduction path and the cooling water discharge path connected to the cooling water flow path are provided in the one side closing member.

Further, in accordance with an eighth aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus as recited in the fifth aspect, wherein the fuel introduction path connected to the fuel distribution path and the cooling water introduction path connected to the cooling water flow path are provided in the one side closing member, and the cooling water discharge path connected to the cooling water flow path is provided in the another side closing member.

Further, in accordance with a ninth aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus as recited in the first aspect, wherein heat radiating fins disposed along the line X—X in the direction of the longitudinal axis of the fuel distribution pipe are provided in any one or both of an outer peripheral wall of the fuel distribution path and an inner peripheral wall of the cooling water flow path.

Further, in accordance with a tenth aspect of the present invention, there is provided a fuel distribution pipe in a fuel injection apparatus as recited in the first aspect, wherein the cooling water flow path is sectioned into a first cooling water flow path and a second cooling water flow path along the line X—X in the direction of the longitudinal axis by a partition wall, the first cooling water flow path and the second cooling water flow path are communicated by another end portion of the fuel distribution pipe, the cooling water introduction path is opened to the first cooling water flow path open to the one end portion, and the cooling water discharge path is opened to the second cooling water flow path open to the one end portion.

In accordance with the first aspect mentioned above, the fuel within the fuel distribution path of the fuel distribution pipe is cooled by the cooling water within the cooling water flow path provided in the outer periphery of the fuel distribution path, and when the heat within the engine room is applied to the fuel distribution pipe, the heat is cooled by the

cooling water within the cooling water flow path so as to be prevented from being transmitted, thereby preventing the temperature of the fuel flowing within the fuel distribution path from being increased.

In accordance with the second aspect, since the cooling water within the cooling water flow path flows into from the cooling water introduction path and is discharged from the cooling water discharge path after flowing within the cooling water flow path so as to circulate within the cooling water flow path, it is possible to increase a cooling effect of the fuel within the fuel distribution path.

In accordance with the third aspect, the fuel distribution pipe is formed by a casting process, the opening of the one end portion of the fuel distribution pipe is closed by the one side closing member, and the inner portion of the fuel distribution pipe is sectioned into the fuel distribution path and the cooling water flow path. Further, since the fuel introduction path and the cooling water introduction path are provided in the one side closing member, it is possible to easily form the flow paths.

In accordance with the fourth aspect, since the fuel introduction path, the cooling water introduction path and the cooling water discharge path are provided in the one side closing member, it is possible to circulate the cooling water within the cooling water flow path by a simple structure, and it is possible to increase a cooling effect.

In accordance with the fifth aspect, the fuel distribution pipe is formed of the drawn material and the openings at both ends thereof are closed by the one side closing member and the another side closing member, thereby forming the fuel distribution pipe provided with the fuel distribution path and the cooling water flow path sectioned from each other, so that it is possible to reduce the manufacturing cost.

In accordance with the sixth aspect, since the fuel introduction path and the cooling water introduction path are provided in the one side closing member in the fuel distribution pipe made of the drawn material, it is possible to easily form the flow paths.

In accordance with the seventh aspect, since the fuel introduction path, the cooling water introduction path and the cooling water discharge path are provided in the one side closing member in the fuel distribution pipe made of the drawn material, it is possible to circulate the cooling water within the cooling water flow path in accordance with a simple structure, and it is possible to increase a cooling effect.

In accordance with the eighth aspect, in the fuel distribution pipe made of the drawn material, since the fuel introduction path and the cooling water introduction path are provided in the one side closing member and the cooling water discharge path is provided in the another side closing member, it is possible to securely circulate the cooling water within the cooling water path, so that it is possible to further improve a cooling property of the fuel within the fuel distribution path.

In accordance with the ninth aspect, since the heat radiating area is increased by the heat radiating fin, it is possible to increase a heat radiating property with respect to the cooling water and it is possible to further effectively restrict an increase of temperature of the fuel flowing within the fuel distribution path.

In accordance with the tenth aspect, the cooling water path is sectioned into the first cooling water path and the second cooling water path by the partition wall, and the paths are connected at the another end and are respectively sectioned at the one end and opened.

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Since the cooling water flows downstream through the first cooling water path and thereafter U-turns toward and flows through the second cooling water path, it is possible to largely improve the cooling effect of the fuel within the fuel distribution path. Further, it is possible to improve a rigidity of the fuel distribution pipe by the partition wall.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical cross sectional view showing an embodiment of a fuel distribution pipe in a fuel injection apparatus in accordance with the present invention;

FIG. 2 is a vertical cross sectional view in a line A—A in FIG. 1;

FIG. 3 is a vertical cross sectional view in a line B—B in FIG. 1;

FIG. 4 is a vertical cross sectional view of a main portion of one side closing member showing another embodiment in accordance with the present invention;

FIG. 5 is a vertical cross sectional view of a main portion of one side closing member showing the other embodiment in accordance with the present invention;

FIG. 6 is a vertical cross sectional view showing the other embodiment in accordance with the present invention;

FIG. 7 is a vertical cross sectional view in a line C—C in FIG. 6;

FIG. 8 is a vertical cross sectional view in a line D—D in FIG. 6;

FIG. 9 is a vertical cross sectional view in a line E—E in FIG. 6;

FIG. 10 is a vertical cross sectional view of a main portion of one side closing member showing the other embodiment in accordance with the present invention;

FIG. 11 is a vertical cross sectional view of a main portion of one side closing member showing the other embodiment in accordance with the present invention;

FIG. 12 is a vertical cross sectional view showing the other embodiment in accordance with the present invention;

FIG. 13 is a vertical cross sectional view of a fuel distribution pipe showing the other embodiment in accordance with the present invention;

FIG. 14 is a vertical cross sectional view of a fuel distribution pipe showing the other embodiment in accordance with the present invention;

FIG. 15 is a vertical cross sectional view of a fuel distribution pipe showing the other embodiment in accordance with the present invention; and

FIG. 16 is a vertical cross sectional view in a line G—G in FIG. 15.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A description will be given below of an embodiment of a fuel distribution pipe in a fuel injection apparatus in accordance with the present invention with reference to FIGS. 1 to 3.

FIG. 1 is a vertical cross sectional view of a fuel distribution pipe along a longitudinal direction, FIG. 2 is a vertical cross sectional view in a line A—A in FIG. 1, and FIG. 3 is a vertical cross sectional view in a line B—B in FIG. 1.

Reference numeral 1 denotes a fuel distribution pipe, in which a fuel distribution path 2 is pierced along a line X—X in a direction of a longitudinal axis and the fuel distribution path 2 is open toward one end portion 1A thereof.

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Further, a cooling water flow path 3 is pierced on an outer periphery of the fuel distribution path 2 so as to extend along the line X—X in the direction of the longitudinal axis of the fuel distribution path 2 and surround the fuel distribution path 2, and this cooling water flow path 3 is also opened toward the one end portion 1A thereof.

Reference numeral 4 denotes an injection valve supporting hole for inserting a rear end portion JA of a fuel injection valve J so as to support, and the hole is pierced so as to vertically crosses toward the fuel distribution path 2 and is opened.

In the present embodiment, three injection valve supporting holes 4 are pierced along the line X—X in the direction of the longitudinal axis, however, the number thereof may be suitably selected.

Reference numeral 5 denotes a fuel introduction path, which is opened toward the fuel distribution path 2.

Reference numeral 6A denotes a cooling water introduction path for supplying cooling water toward the cooling water flow path 3, and reference numeral 6B denotes a cooling water discharge path for discharging the cooling water from the cooling water flow path 3. These paths are both opened to the cooling water flow path 3.

The cooling water introduction path 6A and the cooling water discharge path 6B are connected to a pipe for a radiator for cooling an engine or the like.

The fuel distribution path 2 and the cooling water flow path 3 are particularly opened to a bottom portion 1C of a circular hole 1B provided so as to be opened in one end portion 1A, and the circular hole 1B is closed by one side closing member 7.

The one side closing member 7 is formed of a large-diameter cylinder portion 7A inserted and arranged to the circular hole 1B in a liquid-tight manner and a small-diameter cylinder portion 7B inserted and arranged within the fuel distribution path 2 in a liquid-tight manner.

Then, the fuel distribution path 2, the cooling water flow path 3 and an atmospheric air are shut in a liquid-tight manner by inserting and arranging the small-diameter cylinder portion 7B of the one side closing member 7 within the fuel distribution path 2, and the cooling water flow path 3 and the atmospheric air are shut in a liquid-tight manner by inserting and arranging the large-diameter cylinder portion 7A in the circular hole 1B. Then, in a state mentioned above, an outer end of the one end portion 1A of the fuel distribution pipe 1 is inward caulked toward the above of the large-diameter cylinder portion 7A of the one side closing member 7, where by the one side closing member 7 is fixed to the fuel distribution pipe 1.

In this case, reference numeral 8 denotes a seal ring made of a rubber material for sealing in a liquid-tight manner.

In accordance with the structure mentioned above, the fuel distribution path 2 disposed along the line X—X in the direction of the longitudinal axis is formed in an inner portion of the fuel distribution pipe 1, the cooling water flow path 3 disposed along the line X—X in the direction of the longitudinal axis is formed on the outer periphery of the fuel distribution path 2 in such a manner as to be sectioned from the fuel distribution path 2, the injection valve supporting hole 4 and the fuel introduction hole 5 are opened to an inner portion of the fuel distribution path 2, and the cooling water introduction path 6A and the cooling water discharge path 6B are opened to the cooling water flow path 3.

Then, a fuel pipe 9 connected to a fuel source (not shown) is connected and arranged to the fuel introduction path 5,

and a rear end portion JA of a fuel injection valve J is inserted and arranged to the injection valve supporting hole 4.

The fuel distribution pipe 1 mentioned above is structured, as shown in FIG. 2, such as to be fixed to an intake pipe 11 via a flange portion 1D extending to a right side direction by a bolt 10, at this time, the fuel injection valve J is gripped between the fuel distribution pipe 1 and the intake pipe 11 via an elastic member 12, and an injection hole (not shown) at a front end of the fuel injection valve J is opened and arranged toward an inner portion of the intake pipe 11.

Further, the fuel having a pressure increased by a fuel pump driven in correspondence to an operation of an engine is supplied into the fuel distribution path 2 of the fuel distribution pipe 1 via the fuel pipe 9 and the fuel introduction path 5, and the fuel within the fuel distribution path 2 is injected and supplied into the intake pipe 11 via the fuel injection valve J opened in response to a valve opening signal output from the ECU.

On the other hand, the cooling water branched from a water pipe in the radiator is supplied to the cooling water introduction path 6A, and the cooling water is supplied into the cooling water flow path 3 within the fuel distribution pipe 1, circulates through the cooling water flow path 3 and thereafter is returned to the water pipe in the radiator from the cooling water discharge path 6B again.

In accordance with the structure mentioned above, even in the case that the heated fuel is supplied into the fuel distribution path 2 of the fuel distribution pipe 1 from the fuel pipe 9, the fuel is cooled by the cooling water within the cooling water flow path 3 flowing so as to surround the outer periphery of the fuel distribution path 2, so that an increase of temperature of the fuel is restricted.

On the other hand, the fuel distribution pipe 1 is arranged near the engine so as to be heated, whereby the temperature of the fuel distribution pipe 1 itself is increased to make the temperature of the fuel within the fuel distribution path 2 increase, however, since the cooling water flow path 3 exists between the outer peripheral wall of the fuel distribution pipe 1 and the fuel distribution path 2 so as to make it hard to transmit the increased temperature of the outer peripheral wall of the fuel distribution pipe 1 to the fuel distribution path 2, the fuel within the fuel distribution path 2 is never heated and the temperature thereof is not increased.

Accordingly, since it is possible to restrict an increase of temperature of the fuel of the fuel distribution path 2 within the fuel distribution pipe 1 during the operation of the engine, it is possible to prevent vapors from being generated in the fuel, whereby the fuel can be continuously supplied stably and accurately toward the inner portion of the intake pipe, so that it is possible to largely improve an operation property of the engine.

Further, since the fuel injection valve J repeats the opening and closing operations of the injection hole at the front end thereof during the operation of the engine, a pressure change is generated within the fuel distribution path 2 and there is a case that a sound is generated toward the outside.

However, in accordance with the present invention, since the outer periphery of the fuel distribution path 2 is surrounded by the cooling water flow path 3 along the line X—X in the direction of the longitudinal axis, the sound generated within the fuel distribution path 2 is shut by the cooling water of the cooling water flow path 3, whereby it is possible to largely reduce the sound from the outer periphery of the fuel distribution pipe 1 toward the outside.

Then, in accordance with the structure in which the cooling water introduction path 6A and the cooling water discharge path 6B are opened to the cooling water flow path, since the cooling water is always circulated within the cooling water flow path 3 during the operation of the engine, it is possible for the cooling water to continuously absorb and radiate a heat, so that it is possible to effectively restrict an increase of temperature of the fuel within the fuel distribution path 2.

A description will be given of another embodiment with reference to FIG. 4.

FIG. 4 shows the one end portion 1A of the fuel distribution pipe 1 and the one side closing member 7.

The fuel distribution pipe 1 is structured such that the fuel distribution path 2 and the cooling water flow path 3 are formed along the line X—X in the direction of the longitudinal axis by a casting process such as an injection molding or the like and the flow paths 2 and 3 are opened to the bottom portion 1C of the circular hole 1B provided in the one end portion 1A.

In this case, the injection valve supporting hole 4 and the cooling water discharge path 6B (both are omitted and not illustrated) maybe formed by a casting process or by a machining process.

The one side closing member 7 arranged in the circular hole 1B of the one end portion 1A has the large-diameter cylinder portion 7A and the small-diameter cylinder portion 7B in the same manner as that in FIG. 1, and further has the following structure.

Reference numeral 7C is a cooling water groove portion formed in an inner portion near the outer periphery of the large-diameter cylinder portion 7A, and the cooling water groove portion 7C is formed so as to be opened to a left end portion 7J of the large-diameter cylinder portion 7A in such a manner as to face to the cooling water flow path 3 opening to the bottom portion 1C of the circular hole 1B.

Reference numeral 7D denotes a fuel introduction path provided in such a manner as to extend through an approximate center of the large-diameter cylinder portion 7A and the small-diameter cylinder portion 7B, one end thereof is protruded rightward in the figure so as to form a pipe shape and opened, and another end thereof is opened to a left end surface of the small-diameter cylinder portion 7B.

Reference numeral 7E denotes a cooling water introduction path provided in a side portion of the large-diameter cylinder portion 7A, and the cooling water introduction path 7E is opened within the cooling water groove portion 7C.

In this case, in the embodiment mentioned above, the fuel introduction path 5, the fuel pipe 9 and the cooling water introduction path 6A illustrated in FIG. 1 are not required.

Then, the large-diameter cylinder portion 7A of the one side closing member 7 is inserted and arranged in the circular hole 1B in a liquid-tight manner, the small-diameter cylinder portion 7B is inserted and arranged within the fuel distribution path 2 in a liquid-tight manner, and the one end portion 1A of the fuel distribution pipe 1 is inward caulked toward the large-diameter cylinder portion 7A in this state, whereby the closing member 7 is fixed to one end of the fuel distribution pipe 1.

Accordingly, the fuel introduction path 7D is connected and opened to the fuel distribution path 2 via a left end surface of the small-diameter cylinder portion 7B, and the cooling water introduction path 7E is connected to the cooling water flow path 3 via the cooling water groove portion 7C.

In accordance with the structure mentioned above, it is possible to reduce the number of the parts and to make the shape of the fuel distribution pipe 1 simple so as to reduce a producing cost by forming the fuel distribution pipe 1 provided with the fuel distribution path 2 and the cooling water flow path 3 by a casting process and forming the fuel introduction path 7D and the cooling water introduction path 7E integrally with the one side closing member 7 for closing the one end portion 1A of the fuel distribution pipe 1. Further, in accordance with the structure obtained by providing the cooling water introduction path 7E in the one side closing member 7 and arranging and fixing the large-diameter cylinder portion 7A of the one side closing member 7 to the circular hole 1B of the one end portion 1A, it is possible to freely arrange the opening position of the cooling water introduction path 7E by rotating the large-diameter cylinder portion 7A so as to position and fix, so that it is possible to improve a freedom of the pipe of the cooling water path.

A description will be given of the other embodiment with reference to FIG. 5.

FIG. 5 shows a structure in which a cooling water discharge path 7F is added to the embodiment shown in FIG. 4.

The cooling water discharge path 7F is provided in a side portion of the large-diameter cylinder portion 7A of the one side closing member 7, and the cooling water discharge path 7F is communicated with the cooling water flowpath 3 via the cooling water groove portion 7C.

In accordance with the present embodiment, the cooling water flows into the cooling water flow path 3 via the cooling water groove portion 7C from the cooling water introduction path 7E and next is discharged from the cooling water groove portion 7C via the cooling water discharge path 7F. In accordance with the structure mentioned above, since the fuel introduction path 7D, the cooling water introduction path 7E and the cooling water discharge path 7F are provided in the one side closing member 7, it is not necessary to provide each of the flow paths 7D, 7E and 7F in the fuel distribution pipe 1 itself, and the structure of the fuel distribution pipe 1 itself is further made simple so as to make it easy to produce the fuel distribution pipe 1, thereby further reducing a producing cost, and since each of the flow paths is formed in the one side closing member 7 together, it is possible to achieve reduction of parts cost.

Next, a description will be given of the other embodiment with reference to FIGS. 6 to 9.

FIG. 6 is a vertical cross sectional view of the fuel distribution pipe along a longitudinal direction.

FIG. 7 is a vertical cross sectional view in a line C—C in FIG. 6.

FIG. 8 is a vertical cross sectional view in a line D—D in FIG. 6.

FIG. 9 is a vertical cross sectional view in a line E—E in FIG. 6.

Reference numeral 20 denotes a fuel distribution pipe, in which a fuel distribution path 21 is pierced along a line X—X in a direction of a longitudinal axis and a cooling water flow path 22 is pierced along the line X—X in the direction of the longitudinal axis so as to surround the fuel distribution path 21. The fuel distribution pipe 20 including the fuel distribution path and the cooling water flow path 22 is formed continuously from one end portion 20A toward another end portion 20B in the line X—X in the direction of the longitudinal axis by a drawing process.

Reference numeral 20C denotes a fuel boss, which is formed below the fuel distribution pipe 20 in FIG. 7 and in which an injection valve supporting hole and a fuel introduction hole mentioned below are pierced, reference numeral 20D denotes a flange portion formed in a lower right side portion in FIG. 7, and reference numeral 20E denotes a cooling water boss formed in a center right side portion in FIG. 7.

Then, the fuel boss 20C, the flange portion 20D and the cooling water boss 20E are also formed continuously from the one end portion 20A toward the another end portion 20B by a drawing process. In other words, a cross sectional shape shown in FIG. 7 is formed by a drawing process as a raw material.

Further, the following working process is applied to the fuel distribution pipe 20 formed by a drawing process. Reference numeral 23 denotes an injection valve supporting hole for inserting and supporting a rear end portion of a fuel injection valve J. The injection valve supporting hole 23 is pierced so as to be opened from the lower end of the fuel boss 20C toward the inner portion of the fuel distribution path 21.

Further, reference numeral 24 denotes a fuel introduction hole for pressure inserting and arranging the fuel pipe 9. The fuel introduction hole 24 is pierced so as to be opened from the lower end of the fuel boss 20C toward the inner portion of the fuel distribution path 21.

These elements are well shown in FIG. 6.

Further, reference numeral 25A denotes a cooling water introduction path and reference numeral 25B denotes a cooling water discharge path. These elements are pierced in the cooling water boss 20E so as to be opened to the cooling water flow path 22. The cooling water discharge path 25B is well shown in FIG. 9.

Further, reference numeral 26 denotes a bolt mounting hole pierced through the flange portion 20D. This element is well shown in FIG. 8.

Further, a circular hole 20G provided with a bottom portion 20F is pierced in the one end portion 20A and the another end portion 20B in the fuel distribution pipe 20, one end (a right end) of each of the fuel distribution path 21 and the cooling water flow path 22 is opened to the bottom portion 20F of the circular hole 20G in one side, and another end (a left end) of each of the fuel distribution path 21 and the cooling water flow path 22 is opened to the bottom portion 20F of the circular hole 20G in another side.

Then, the following structure is assembled in the fuel distribution pipe 20 formed by a drawing process.

The rear end portion of the fuel injection valve J is inserted and arranged in the injection valve supporting hole 23 in a liquid-tight manner. This structure is well shown in FIG. 8.

Further, the fuel pipe 9 connected to the fuel pump (not shown) is pressure inserted to the fuel introduction hole 24.

The one side closing member 27 is formed of a large-diameter cylinder portion 27A inserted and arranged to a circular hole 20G in one side in a liquid-tight manner and a small-diameter cylinder portion 27B inserted and arranged within the one side fuel distribution path 21 in a liquid-tight manner, the fuel distribution path 21, the cooling water flow path 22 and the atmospheric air are shut in a liquid-tight manner by inserting and arranging the small-diameter cylinder portion 27B in the one side closing member into one side of the fuel distribution path 21, and the cooling water flow path 22 and the atmospheric air are shut in a liquid-tight

manner by inserting and arranging the large-diameter cylinder portion 27A into the circular hole 20G in one side.

Then, in the state mentioned above, one end portion 20A of the fuel distribution pipe 20 is inward caulked toward the above of the large-diameter cylinder portion 27A of the one side closing member 27, whereby the one side closing member 27 is fixed to the one end portion 20A of the fuel distribution pipe 20.

The another side closing member 28 is formed of a large-diameter cylinder portion 28A inserted and arranged to a circular hole 20G in another side in a liquid-tight manner and a small-diameter cylinder portion 28B inserted and arranged within the fuel distribution path 21 in another side in a liquid-tight manner, the fuel distribution path 21, the cooling water flow path 22 and the atmospheric air are shut in a liquid-tight manner by inserting and arranging the small-diameter cylinder portion 28B in the another side closing member into another side of the fuel distribution path 21, and the cooling water flow path 22 and the atmospheric air are shut in a liquid-tight manner by inserting and arranging the large-diameter cylinder portion 28A into the circular hole 20G in another side.

Then, in the state mentioned above, the another end portion 20B of the fuel distribution pipe 20 is inward caulked toward the above of the large-diameter cylinder portion 28A of the another side closing member 28, whereby the another side closing member 28 is fixed to the another end portion 20B of the fuel distribution pipe 20.

In this case, reference numeral 8 denotes a seal ring made of a rubber material for sealing in a liquid-tight manner.

The fuel distribution pipe 20 having the structure mentioned above is structured such as to be fixed to the intake pipe 11 via the bolt mounting hole 26 in the flange portion 20D by the bolt 10, and at this time, the fuel injection valve J is held between the fuel distribution pipe 20 and the intake pipe 11 via the elastic member 12. This structure is well shown in FIG. 8.

In accordance with the fuel distribution pipe 20 structured as mentioned above, the fuel within the fuel distribution pipe 21 is cooled by the cooling water within the cooling water flow path 22 in the same manner as that of the fuel distribution pipe 1 shown in FIG. 1, where by the temperature of the fuel is prevented from being increased. Further, it is possible to reduce the sound generated from the fuel distribution pipe 20 toward the outside.

Further, in accordance with the present embodiment, since the fuel distribution path 21 and the cooling water flow path 22 are formed by drawing the fuel distribution pipe 20 and the opening of each of the flow path is closed and formed in a sectional manner by the one side and another side closing members 27 and 28, it is possible to reduce a producing cost thereof.

A description will be given of the other embodiment with reference to FIG. 10.

FIG. 10 shows the one end portion 20A of the fuel distribution pipe 20 and the one side closing member 27 in FIG. 6.

The one side closing member 27 arranged in the circular hole 20G of the one end portion 20A has the large-diameter cylinder portion 27A and the small-diameter cylinder portion 27B in the same manner as that of FIG. 6 and further has the following structure.

Reference numeral 27C denotes a cooling water groove portion formed in the inner portion of the large-diameter cylinder portion 27A. The cooling water groove portion 27C

is arranged so as to face to the cooling water flow path 21 opened to the bottom portion 20F of the circular hole 20G.

Reference numeral 27D denotes a fuel introduction path extending through the large-diameter cylinder portion 27A and the small-diameter cylinder portion 27B and having one end rightward protruding so as to be opened and another end opened to a left end surface of the small-diameter cylinder portion 27B.

Reference numeral 27E denotes a cooling water introduction path provided in a side portion of the large-diameter cylinder portion 27A. The cooling water introduction path 27E is opened into the cooling water groove 27C.

In the present embodiment, the fuel introduction hole 24 and the cooling water introduction hole 25A in FIG. 6 are not required. Further, the one side closing member 27 is fixed and arranged within the circular hole 20G in one side of the fuel distribution pipe 20, the fuel introduction path 27D is connected to the fuel pump, and the cooling water introduction path 27E is connected to a cooling pipe of a radiator or the like.

Accordingly, the fuel having the pressure increased by the fuel pump is supplied into the fuel distribution path 21 via the fuel introduction path 27D of the one side closing member 27, and on the other hand, the cooling water is supplied into the cooling water flow path 21 via the cooling water introduction path 27E and the cooling water groove portion 27C of the one side closing member 27.

In accordance with the structure mentioned above, the fuel distribution pipe 20 provided with the fuel distribution path 21 and the cooling water flow path 22 is formed by a drawing process, and the fuel introduction path 27D and the cooling water introduction path 27E are integrally formed in the one side closing member 27 closing the one end portion 20A of the fuel distribution pipe 20, whereby it is possible to reduce the number of the parts and to reduce a producing cost thereof.

A description will be given of the other embodiment with reference to FIG. 11.

FIG. 11 shows a structure in which a cooling water discharge path 27F is added to the embodiment shown in FIG. 10. The cooling water discharge path 27F is provided in a side portion of the large-diameter cylinder portion 27A of the one side closing member 27, and the cooling water discharge path 27F is communicated with the cooling water groove portion 27C. In accordance with the present embodiment, the cooling water flows into the cooling water flow path 21 from the cooling water introduction path 27E via the cooling water groove portion 27C and next is discharged from the cooling water groove portion 27C via the cooling water discharge path 27F. In accordance with the structure mentioned above, since the fuel introduction path 27D, the cooling water introduction path 27E and the cooling water discharge path 27F are provided in the one side closing member 27, it is not necessary to provide each of the flow paths 27D, 27E and 27F in the fuel distribution pipe 20 itself, and the structure of the fuel distribution pipe 20 itself is further made simple so as to reduce a producing cost, and since each of the flow paths is formed in the one side closing member 27 together, it is possible to achieve reduction of parts cost.

Next, a description will be given of the other embodiment with reference to FIG. 12.

In this embodiment, the structure of the one side closing member 27 and the another side closing member 28 is different from the embodiment shown in FIG. 6, and among them, one side closing member 27 shown in FIG. 10 is

employed for the one side closing member 27. Accordingly, a description of the one side closing member 27 will be omitted.

The another side closing member 28 is formed of a large-diameter cylinder portion 28A inserted and arranged to the circular hole 20G in another side in a liquid-tight manner and a small-diameter cylinder portion 28B inserted and arranged into the fuel distribution path 21 in another side in a liquid-tight manner, and a cooling water groove portion 28C facing to the cooling water flow path 21 opening to the bottom portion 20F of the circular hole 20G is formed in the inner portion of the large-diameter cylinder portion 28A.

Further, a cooling water discharge path 28D connected to the cooling water groove portion 28C is formed in the large-diameter cylinder portion 28A of the another side closing member 28.

The small-diameter cylinder portion 28B of the another side closing member 28 is inserted and arranged into the fuel distribution path 21 in the another side, whereby the fuel distribution path 21, the cooling water flow path 22 and the atmospheric air are shut, and the large-diameter cylinder portion 28A is inserted and arranged into the circular hole 20G, whereby the cooling water flow path 22 and the atmospheric air are shut, so that the cooling water discharge path 28D is communicated via the cooling water groove portion 28C.

In accordance with the structure mentioned above, the fuel having the pressure increased by the fuel pump is supplied into the fuel distribution path 21 of the fuel distribution pipe 20 through the fuel introduction path 27D provided in the one side closing member 27.

Further, the cooling water supplied to the cooling water introduction path 27E of the one side closing member 27 is supplied into the cooling water flow path 22 of the fuel distribution pipe 20 via the cooling water groove portion 27C of the one side closing member 27, next flows downward within the cooling water flow path 22 from a left portion toward a right portion, and next is discharged from the cooling water discharge path 28D via the cooling water groove portion 28C of the another side closing member 28.

As mentioned above, since the cooling water is positively flown downward from one side of the cooling water flow path 22 toward another side, it is possible to significantly effectively cool the fuel within the fuel distribution path 21.

Further, in the case that the fuel introduction path 27D and the cooling water introduction path 27E are provided in the one side closing member 27 and the cooling water discharge path 28D is provided in the another side closing member 28, it is not necessary to provide the flow path in the fuel distribution pipe 20 itself, so that it is possible to make a shape of the fuel distribution pipe 20 simple and it is particularly effective at a time of forming the fuel distribution pipe 20 by a drawing process.

A description will be given of the other embodiment with reference to FIG. 13.

FIG. 13 corresponds to a cross section vertically crossing to the line X—X in the direction of the longitudinal axis of the fuel distribution pipe.

Reference numeral 20P denotes a heat radiating fin provided on an inner peripheral wall 20S of the cooling water flow path 22, and a plurality of the heat radiating fins 20P are formed and provided along the line X—X in the direction of the longitudinal axis of the fuel distribution pipe.

In accordance with the structure mentioned above, since the heat of the fuel distribution pipe 20 heated by the fuel

flowing within the fuel distribution path 21 and the atmosphere of the fuel distribution pipe 20 is effectively radiated toward the cooling water flowing through the cooling water flow path 22 by the heat radiating fins 20P, it is possible to effectively restrict an increase of temperature of the fuel within the fuel distribution path 21.

Further, it is effective in view of increasing an area for heat radiation by the heat radiating fins 20P to form the heat radiating fins 20P along the line X—X in the direction of the longitudinal axis of the fuel distribution pipe 20, and in accordance with the structure, it is significantly easy to form the heat radiating fins 20P as above when the fuel distribution pipe is formed by an injection molding process and a drawing process.

FIG. 14 shows the other embodiment of the heat radiating fins 20P. The heat radiating fins 20P are provided on an outer peripheral wall 20T of the fuel distribution path 21 and a plurality of the heat radiating fins 20P are formed and provided along the line X—X in the direction of the longitudinal axis of the fuel distribution pipe in the same manner as that of the embodiment mentioned above.

In accordance with the present embodiment, since the heat radiating fins 20P are provided on the outer periphery of the fuel distribution path 21, it is possible to more effectively restrict an increase of temperature of the fuel within the fuel distribution path 21.

A description will be given of the other embodiment with reference to FIGS. 15 and 16.

FIG. 15 is a vertical cross sectional view vertically crossing to a direction of a longitudinal axis of a fuel distribution pipe.

FIG. 16 is a vertical cross sectional view in a line G—G in FIG. 15.

A fuel distribution pipe 1 is structured such that a fuel distribution path 2 and a cooling water flow path 3 are opened to a bottom portion 1C of a circular hole 1B in one end portion 1A, and the fuel distribution path 2 and the cooling water flow path 3 extend toward the another side along the line X—X in the longitudinal axis and opened to the bottom portion 1C of the circular hole 1B in another end portion 1D.

Reference numeral 1E denotes a partition wall formed within the cooling water flow path 3 along the line X—X in the direction of the longitudinal axis of the fuel distribution pipe 1. The partition wall 1E sections the cooling water flow path 3 into a first cooling water flow path 3A and a second cooling water flowpath 3B along the line X—X in the direction of the longitudinal axis.

Accordingly, one end of each of the first cooling water flow path 3A and the second cooling water flow path 3B is opened to the bottom portion 1C of the circular hole 1B in one side, and another end of each of the first cooling water flow path 3A and the second cooling water flow path 3B is opened to the bottom portion 1C of the circular hole 1B in another end.

Reference numeral 30 denotes one side closing member arranged in the one end portion 1A of the fuel distribution pipe 1. The one side closing member is provided with a large-diameter cylinder portion 30A inserted and arranged to the circular hole 1B in a liquid-tight manner and a small-diameter cylinder portion 30B arranged in the fuel distribution path 2 in a liquid-tight manner, and further a first cooling water groove portion 30C facing to the first cooling water flow path 3A and a second cooling water groove portion 30D facing to the second cooling water flow path 3B are recessed in the large-diameter cylinder portion 30.

The first and second cooling water groove portions 30C and 30D are formed so as to be sectioned and are opened to a step portion 30E in a side of the small-diameter cylinder portion 30B of the large-diameter cylinder portion 30A.

Further, reference numeral 30F denotes a cooling water introduction path opened to the first cooling water groove portion 30C and reference numeral 30G denotes a cooling water discharge path opened to the second cooling water groove portion 30D. Further, reference numeral 30H denotes a fuel introduction path opened to an end portion of the small-diameter cylinder portion 30B.

Then, the small-diameter cylinder portion 30B of the one side closing member 30 is inserted and arranged into one end of the fuel distribution path 2, whereby the fuel distribution path 2, the cooling water flow path 3 (the first and second cooling water flow paths 3A and 3B) and the atmospheric air are shut in a liquid-tight manner, and the large-diameter cylinder portion 30A is inserted and arranged into the circular hole 1B, whereby the cooling water flow path 3 and the atmospheric air are shut in a liquid-tight manner.

Further, the step portion 30E of the large-diameter cylinder portion 30A is brought into contact with the bottom portion 1C of the circular hole 1B, whereby the first cooling water groove portion 30C is communicated with the first cooling water flow path 3A and the second cooling water groove portion 30D is communicated with the second cooling water flow path 3B.

In the state mentioned above, the one side closing member 30 is fixed to the one end portion 1A of the fuel distribution pipe 1.

Reference numeral 40 denotes another side closing member arranged in the another end portion 1D of the fuel distribution pipe 1. The another side closing member is provided with a large-diameter cylinder portion 40A inserted and arranged to the circular hole 1B in a liquid-tight manner and a small-diameter cylinder portion 40B arranged in the fuel distribution path 2 in a liquid-tight manner, and further a communicating groove 40C which faces to the first cooling water flow path 3A and the second cooling water flow path 3B and communicates both of the flow paths 3A and 3B is formed in the large-diameter cylinder portion 40A.

Then, the fuel distribution path 2, the cooling water flow path 3 and the atmospheric air are shut in a liquid-tight manner by inserting and arranging the small-diameter cylinder portion 40B into the another end of the fuel distribution path 2, and the cooling water flow path 3 and the atmospheric air are shut in a liquid-tight manner by inserting and arranging the large-diameter cylinder portion 40A into the circular hole 1B. Further, the first cooling water flow path 3A and the second cooling water flow path 3B which are opened to the bottom portion 1C are communicated with each other by the communicating groove 40C.

In the state mentioned above, the another side closing member 40 is fixed to the another end portion 1D of the fuel distribution pipe 1.

In accordance with the structure mentioned above, the cooling water flows in the manner mentioned below in the fuel distribution pipe 1.

The cooling water entering from the cooling water introduction path 30F flows into the first cooling water flow path 3A from the first cooling water groove portion 30C, flows downstream from one end thereof toward another end, and next flows into the communicating groove 40C of the another side closing member 40.

Further, the cooling water within the communicating groove 40C enters into the second cooling water flow path

3B, the cooling water flows within the second cooling water flow path 3B from another end toward one end and is discharged from the cooling water discharge path 30G via the second cooling water groove portion 30D.

In accordance with the structure mentioned above, since the cooling water is securely U-turned within the fuel distribution pipe 1 so as to generate a two-way flow, it is possible to more effectively cool the fuel within the fuel distribution path 2 so as to restrict an increase of temperature of the fuel.

Further, it is effective in view of increasing a rigidity of the fuel distribution pipe 1 that the partition wall 1E is formed along the direction of the longitudinal axis of the fuel distribution pipe 1, whereby it is possible to achieve an increase of strength of the fuel distribution pipe 1 itself and an improvement of accuracy of a size.

In accordance with the first aspect of the fuel distribution pipe in the fuel injection apparatus of the present invention, since the fuel distribution pipe is pierced along the line X—X in the direction of the longitudinal axis thereof and the injection valve supporting hole for inserting and supporting the rear end portion of the fuel injection valve and the fuel introduction path for supplying the fuel having the pressure increased by the fuel pump are continuously provided in the fuel distribution path of the fuel distribution pipe, and the cooling water flow path extending along the line X—X in the direction of the longitudinal axis of the fuel distribution path and sectioned from the fuel distribution path is provided on the outer periphery of the fuel distribution path, thereby introducing the cooling water into the cooling water flow path, the fuel within the fuel distribution path is cooled within the fuel distribution pipe by the cooling water within the cooling water flow path surrounding the fuel distribution path, whereby it is possible to restrict an increased of temperature of the fuel so as to stably and accurately supply the fuel, thereby improving an operation property of the engine. Further, since the outer periphery of the fuel distribution path is surrounded by the cooling water flow path, it is possible to prevent the sound generated within the fuel distribution path from being transmitted to the outside.

Further, in accordance with the structure made such that the cooling water introduction path and the cooling water discharge path are opened to the cooling water flowpath, thereby circulating the cooling water within the cooling water flow path, it is possible to improve an effect of cooling the fuel within the fuel distribution path.

Further, in accordance with the structure made such that the fuel distribution path and the cooling water flow path are formed within the fuel distribution pipe in a sectional manner by forming the fuel distribution path and the cooling water flow path formed in the fuel distribution pipe so as to be opened in the one end portion by a casting process and closing the one end portion by the one side closing member, and the fuel introduction path connected to the fuel distribution path and the cooling water introduction path connected to the cooling water flow path are provided in the one side closing member, since the fuel introduction path and the cooling water introduction path are provided in the one side closing member, it is easy to produce the fuel distribution pipe by an injection molding process and it is possible to achieve reduction of a producing cost.

Further, in accordance with the structure made such that the fuel introduction path connected to the fuel distribution path, the cooling water introduction path connected to the cooling water flow path and the cooling water discharge path are provided in the one side closing member, it is further

promoted to concentrate the parts into the one side closing member and it is possible to achieve further reduction of the producing cost.

Further, in accordance with the structure made such that the fuel distribution path disposed along the line X—X in the direction of the longitudinal axis within the fuel distribution pipe is formed so as to be sectioned from the cooling water flow path by forming the fuel distribution path and the cooling water flow path respectively open to the one end portion and the another end portion of the fuel distribution pipe by the one side closing member and the another side closing member, it is possible to provide the fuel distribution pipe by a drawing process, whereby it is possible to reduce the producing cost.

Further, in accordance with the structure made such that the fuel distribution pipe is formed by a drawing process and the fuel introduction path connected to the fuel distribution path and the cooling water introduction path connected to the cooling water flow path are provided in the one side closing member, it is not necessary to provide the fuel introduction path and the cooling water introduction path in the fuel distribution pipe itself, and it is easy to form the fuel distribution pipe by a drawing process.

Further, in accordance with the structure made such that the fuel distribution pipe is formed by a drawing process and the fuel introduction path connected to the fuel distribution path and the cooling water introduction path and the cooling water discharge path connected to the cooling water flow path are provided in the one side closing member, it is more easy to form the fuel distribution pipe by a drawing process.

Further, in accordance with the structure made such that the fuel introduction path connected to the fuel distribution path and the cooling water introduction path connected to the cooling water flow path are provided in the one side closing member, and the cooling water discharge path connected to the cooling water flow path is provided in the another side closing member, it is possible to securely flow the cooling water within the cooling water flow path from the one side to the another side and it is possible to improve an effect of cooling the fuel within the fuel distribution path.

Further, in accordance with the structure made such that the heat radiating fins disposed along the line X—X in the direction of the longitudinal axis of the fuel distribution pipe are provided in any one or both of the outer peripheral wall of the fuel distribution path and the inner peripheral wall of the cooling water flow path, it is possible to increase an effect of radiating the heat of the fuel distribution pipe itself and the fuel distribution path, so that it is possible to further restrict an increase of temperature of the fuel.

Further, in accordance with the structure made such that the cooling water flow path is sectioned into the first cooling water flow path and the second cooling water flow path along the line X—X in the direction of the longitudinal axis by the partition wall, the first cooling water flow path and the second cooling water flow path are communicated by the another end portion of the fuel distribution pipe, the cooling water introduction path is opened to the first cooling water flow path open to the one end portion, and the cooling water discharge path is opened to the second cooling water flow path open to the one end portion, it is possible to U-turn the cooling water within the cooling water path so as to improve a cooling effect and it is possible to increase a rigidity of the fuel distribution pipe by the partition wall.

What is claimed is:

1. A fuel distribution pipe in a fuel injection apparatus which increase a pressure of a fuel within a fuel source by a fuel pump to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel injection valve attached to the fuel distribution pipe, characterized that the fuel distribution path is pierced along a line X—X in a direction of a longitudinal axis of the fuel distribution pipe and an injection valve supporting hole for inserting and supporting a rear end portion of the fuel injection valve and a fuel introduction path for supplying a fuel having a pressure increased by a fuel pump are continuously provided in said fuel distribution path of the fuel distribution pipe, and that a cooling water flow path extending along the line X—X in the direction of the longitudinal axis of the fuel distribution path and sectioned from the fuel distribution path is provided on an outer periphery of said fuel distribution path, thereby introducing a cooling water into said cooling water flow path;

wherein a cooling water introduction path and a cooling water discharge path are opened to said cooling water flow path, thereby circulating the cooling water within the cooling water flow path;

wherein the fuel distribution path and the cooling water flow path are formed within the fuel distribution pipe in a sectional manner by forming the fuel distribution path and the cooling water flow path formed in said fuel distribution pipe so as to be opened in one end portion by a casting process and closing said one end portion by one side closing member, and the fuel introduction path connected to the fuel distribution path and a cooling water introduction path connected to the cooling water flow path are provided in said one side closing member.

2. A fuel distribution pipe in a fuel injection apparatus which increase a pressure of a fuel within a fuel source by a fuel pump to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel injection valve attached to the fuel distribution pipe, characterized that the fuel distribution path is pierced along a line X—X in a direction of a longitudinal axis of the fuel distribution pipe and an injection valve supporting hole for inserting and supporting a rear end portion of the fuel injection valve and a fuel introduction path for supplying a fuel having a pressure increased by a fuel pump are continuously provided in said fuel distribution path of the fuel distribution pipe, and that a cooling water flow path extending along the line X—X in the direction of the longitudinal axis of the fuel distribution path and sectioned from the fuel distribution path is provided on an outer periphery of said fuel distribution path, thereby introducing a cooling water into said cooling water flow path;

wherein a cooling water introduction path and a cooling water discharge path are opened to said cooling water flow path, thereby circulating the cooling water within the cooling water flow path;

wherein the fuel distribution path and the cooling water flow path are formed within the fuel distribution pipe in a sectional manner by forming the fuel distribution path and the cooling water flow path formed in said fuel distribution pipe so as to be opened in one end portion by a casting process and closing said one end portion by one side closing member, and the fuel introduction path connected to the fuel distribution path and a cooling water introduction path connected to the cooling water flow path are provided in said one side closing member;

wherein the fuel introduction path connected to the fuel distribution path, the cooling water introduction path

connected to the cooling water flow path and a cooling water discharge path are provided in said one side closing member.

3. A fuel distribution pipe in a fuel injection apparatus which increase a pressure of a fuel within a fuel source by a fuel pump to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel injection valve attached to the fuel distribution pipe, characterized that the fuel distribution path is pierced along a line X—X in a direction of a longitudinal axis of the fuel distribution pipe and an injection valve supporting hole for inserting and supporting a rear end portion of the fuel injection valve and a fuel introduction path for supplying a fuel having a pressure increased by a fuel pump are continuously provided in said fuel distribution path of the fuel distribution pipe, and that a cooling water flow path extending along the line X—X in the direction of the longitudinal axis of the fuel distribution path and sectioned from the fuel distribution path is provided on an outer periphery of said fuel distribution path, thereby introducing a cooling water into said cooling water flow path;

wherein the fuel distribution path disposed along the line X—X in the direction of the longitudinal axis within the fuel distribution pipe is formed so as to be sectioned from the cooling water flow path by forming the fuel distribution path and the cooling water flow path in said fuel distribution pipe by a drawing process along the line X—X in the direction of the longitudinal axis and closing the fuel distribution path and the cooling water flow path respectively open to one end portion and another end portion of the fuel distribution pipe by one side closing member and another side closing member; wherein the fuel introduction path connected to the fuel distribution path and the cooling water introduction path connected to the cooling water flow path are provided in said one side closing member.

4. A fuel distribution pipe in a fuel injection apparatus which increase a pressure of a fuel within a fuel source by a fuel pump to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel injection valve attached to the fuel distribution pipe, characterized that the fuel distribution path is pierced along a line X—X in a direction of a longitudinal axis of the fuel distribution pipe and an injection valve supporting hole for inserting and supporting a rear end portion of the fuel injection valve and a fuel introduction path for supplying a fuel having a pressure increased by a fuel pump are continuously provided in said fuel distribution path of the fuel distribution pipe, and that a cooling water flow path extending along the line X—X in the direction of the longitudinal axis of the fuel distribution path and sectioned from the fuel distribution path is provided on an outer periphery of said fuel distribution path, thereby introducing a cooling water into said cooling water flow path;

wherein the fuel distribution path disposed along the line X—X in the direction of the longitudinal axis within the fuel distribution pipe is formed so as to be sectioned from the cooling water flow path by forming the fuel distribution path and the cooling water flow path in said fuel distribution pipe by a drafting process along the line X—X in the direction of the longitudinal axis and closing the fuel distribution path and the cooling water flow path respectively open to one end portion and another end portion of the fuel distribution pipe by one side closing member and another side closing member; wherein the fuel introduction path connected to the fuel distribution path and the cooling water introduction

path and the cooling water discharge path connected to the cooling water flow path are provided in said one side closing member.

5. A fuel distribution pipe in a fuel injection apparatus which increase a pressure of a fuel within a fuel source by a fuel pump to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel injection valve attached to the fuel distribution pipe, characterized that the fuel distribution path is pierced along a line X—X in a direction of a longitudinal axis of the fuel distribution pipe and an injection valve supporting hole for inserting and supporting a rear end portion of the fuel injection valve and a fuel introduction path for supplying a fuel having a pressure increased by a fuel pump are continuously provided in said fuel distribution path of the fuel distribution pipe, and that a cooling water flow path extending along the line X—X in the direction of the longitudinal axis of the fuel distribution path and sectioned from the fuel distribution path is provided on an outer periphery of said fuel distribution path thereby introducing a cooling water into said cooling water flow path;

wherein the fuel distribution path, disposed along the line X—X in the direction of the longitudinal axis within the fuel distribution pipe is formed so as to be sectioned from the cooling water flow path by forming the fuel distribution path and the cooling water flow path in said fuel distribution pipe by a drawing process along the line X—X in the direction of the longitudinal axis and closing the fuel distribution path and the cooling water flow path respectively open to one end portion and another end portion of the fuel distribution pipe by one side closing member and another side closing member; wherein the fuel introduction path connected to the fuel distribution path and the cooling water introduction path connected to the cooling water flow path are provided in said one side closing member, and the cooling water discharge path connected to the cooling water flow path is provided in said another side closing member.

6. A fuel distribution pipe in a fuel injection apparatus which increase a pressure of a fuel within a fuel source by a fuel pump to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel injection valve attached to the fuel distribution pipe, characterized that the fuel distribution path is pierced along a line X—X in a direction of a longitudinal axis of the fuel distribution pipe and an injection valve supporting hole for inserting and supporting a rear end portion of the fuel injection valve and a fuel introduction path for supplying a fuel having a pressure increased by a fuel pump are continuously provided in said fuel distribution path of the fuel distribution pipe, and that a cooling water flow path extending along the line X—X in the direction of the longitudinal axis of the fuel distribution path and sectioned from the fuel distribution path is provided on an outer periphery of said fuel distribution path, thereby introducing a cooling water into said cooling water flow path;

wherein said cooling water flow path is sectioned into a first cooling water flow path and a second cooling water flow path along the line X—X in the direction of the longitudinal axis by a partition wall, said first cooling water flow path and said second cooling water flow path are communicated by another end portion of the fuel distribution pipe, the cooling water introduction path is opened to the first cooling water flow path open to the one end portion, and the cooling water discharge path is opened to the second cooling water flow path open to the one end portion.

7. A fuel distribution pipe in a fuel injection apparatus, comprising:

said apparatus which increases pressure of a fuel within a fuel source by a fuel pump to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel injection valve attached to the fuel distribution pipe, characterized that a fuel distribution path formed in the fuel distribution pipe 1 and a cooling water flow path formed around the fuel distribution path open toward a bottom portion of a circular hole opening in a one end portion of the fuel distribution pipe; and

that a one side closing member is provided with a large-diameter cylinder portion, a small-diameter cylinder portion protruding from a left end portion of the large-diameter cylinder portion to another side, a fuel introduction path opening in a left end portion of the small-diameter cylinder portion, a cooling water groove portion recessed in the large-diameter cylinder portion and opening in a left end portion, a cooling water introduction path formed in the large-diameter cylinder portion and communicating within the cooling water groove portion and a cooling water discharge path formed in the large-diameter cylinder portion and communicating within the cooling water groove portion; and

that the small-diameter cylinder portion of the one side closing member is inserted and arranged in a liquid-tight manner within the fuel distribution path opening in the bottom portion of the circular hole, the large-diameter cylinder portion is inserted and arranged in a liquid-tight manner within the circular hole, the fuel introduction path provided in the one side closing member communicates with the fuel distribution path and the cooling water groove portion provided in the one side closing member communicates with the cooling water flow path.

8. A fuel distribution pipe in a fuel injection apparatus, comprising:

said apparatus which increases pressure of a fuel within a fuel source by a fuel pump to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel ejection valve attached to the fuel distribution pipe, wherein a fuel distribution path formed in a fuel distribution pipe and a cooling water flow path formed around the fuel distribution path open toward a bottom portion of a circular hole opening in a first end portion of the fuel distribution pipe and a bottom portion of a circular hole opening in a second end portion; and

wherein a first side closing member is provided with a large-diameter cylinder portion, a small-diameter cylinder portion protruding from a left end portion of the large-diameter cylinder portion to another side, a fuel introduction path opening in a left end portion of the small-diameter cylinder portion, a cooling water groove portion recessed in the large-diameter cylinder portion and opening in the left end portion and a cooling water introduction path formed in the large-diameter cylinder portion and communicating within the cooling water groove portion; and

wherein a second side closing member is provided with a large-diameter cylinder portion, a small-diameter cylinder portion protruding from a right end portion of the large-diameter cylinder portion to one side, a cooling water groove portion recessed in the large-diameter

cylinder portion and opening in the right end portion, and a cooling water discharge path formed in the large-diameter cylinder portion and communicating within the cooling water groove portion; and

wherein the small-diameter cylinder portion of the first side closing member is inserted and arranged in a liquid-tight manner within the fuel distribution path opening in the bottom portion of the circular hole, the large-diameter cylinder portion is inserted and arranged in a liquid-tight manner within the circular hole, the fuel introduction path provided in the first side closing member communicates with the fuel distribution path, the cooling water groove portion provided in the first side closing member communicates with the cooling water flow path, the small-diameter cylinder portion of the second side closing member is inserted and arranged in a liquid-tight manner within the fuel distribution path opening in the bottom portion of the circular hole, the large-diameter cylinder portion is inserted and arranged in a liquid-tight manner within the circular hole and the cooling water groove portion communicates with the cooling water flow path.

9. A fuel distribution pipe in a fuel injection apparatus, comprising:

said apparatus which increases pressure of a fuel within a fuel source by a fuel pump to supply to the fuel distribution pipe and inject and supply the fuel to an engine via a fuel injection valve attached to the fuel distribution pipe, wherein a fuel distribution path formed in a fuel distribution pipe and a first cooling water flow path and a second cooling water flow path formed around the fuel distribution path and formed sectionally each other open toward a bottom portion of a circular hole opening in a first end portion of the fuel distribution pipe and a bottom portion of a circular hole opening in a second end portion; and

wherein a first side closing member is provided with a large-diameter cylinder portion, a small-diameter cylinder portion protruding from a left end portion of the large-diameter cylinder portion to another side, a fuel introduction path opening in a left end portion of the small-diameter cylinder portion, a first cooling water groove portion and a second cooling water groove portion recessed in the large-diameter cylinder portion and opening in the left end portion sectionally each other, a cooling water introduction path formed in the large-diameter cylinder portion and communicating within the first cooling water groove portion and a cooling water discharge path formed in the large-diameter cylinder portion and communicating within the second cooling water groove portion; and

wherein a second side closing member is provided with a large-diameter cylinder portion, a small-diameter cylinder portion protruding from a right end portion of the large-diameter cylinder portion to one side, a cooling water groove portion recessed in the large-diameter cylinder portion by which the first cooling water flow path and the second cooling water flow path opening sectionally to each other in the bottom portion of the circular hole communicate; and

wherein the small-diameter cylinder portion of the one side closing member is inserted and arranged in a liquid-tight manner within the fuel distribution path opening in the bottom portion of the circular hole, the large-diameter cylinder portion is inserted and arranged in a liquid-tight manner within the circular hole, the

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fuel introduction path provided in the first side closing member communicates with the fuel distribution path, the first cooling water groove portion provided in the one side closing member communicates with the first cooling water flow path, the second cooling water groove portion communicates with the second cooling water flow path, the small-diameter cylinder portion of the second side closing member is inserted and arranged in a liquid-tight manner within the fuel dis-

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tribution path opening in the bottom portion of the circular hole, the large-diameter cylinder portion is inserted and arranged in a liquid-tight manner within the circular hole, and the first cooling water flow path and the second cooling water flow path communicate by means of the cooling water groove portion provided in the second side closing member.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,405,712 B1
DATED : June 18, 2002
INVENTOR(S) : Kenichi Nomura

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,

Item [30], **Foreign Application Priority Data**, delete "Mar. 12, 1999" and insert
-- December 3, 1999 --.

Signed and Sealed this

Thirty-first Day of December, 2002

A handwritten signature in black ink, appearing to read "James E. Rogan", with a horizontal line drawn underneath it.

JAMES E. ROGAN
Director of the United States Patent and Trademark Office